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IMPACT OF FUTURE USE OF ELECTRIC CARS IN THE LOS ANGELES REGION

VOLUME III. TASK REPORTS ON IMPACT AND USAGE ANALYSIS

GENERAL RESEARCH CORPORATION

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

OCTOBER 1974

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Impacts of the use of electric cars in the Los Angeles region in 1980-2000 were projected for four-passenger subcompact electric cars using lead-acid and advanced batteries, with urban driving ranges of about 55 and 140 miles, respectively. Data from Los Angeles travel surveys shows that such cars could replace 17 t0 74 percent of future Los Angeles autos with little sacrifice of urban driving. Adequate raw materials and night-time recharging power should be available for such use in the Los Angeles region. Air quality improvements due to the electric cars would be minor because conventional automobile emissions are being drastically reduced. The electric cars would save little energy overall, as compared to conventional subcompacts, but would save considerable amount of petroleum if they were recharged from the nuclear power plants that are planned.
The electric subcompacts would be 20-60% more expensive overall than conventional subcompacts until battery development significantly reduces battery depreciation costs.

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INTRODUCTION

This report is published in three volumes:

Volume 1, Executive Summary and Technical Report

Volume 2, Task Reports on Electric Car Characteristics and Baseline Projections

Volume 3, Task Reports on Impact and Usage Analyses

Volume 1 is a comprehensive account of the effects that electric cars would have on the air quality, energy use, and economy of the Los Angeles region in 1980-2000. Volumes 2 and 3 contain ten individual reports documenting the analyses on which Volume 1 is based. These reports detail the methods, data, assumptions, calculations, and results of the study tasks, and were originally published at the conclusion of each task.

Task reports in Volume 2 project future characteristics of electric cars and of the Los Angeles region in which they would be used, as follows:

1. D. Friedman and J. Andon (Minicars, Inc.) and W. F. Hamilton, Characterization of Battery-Electric Cars for 1980-2000

   Postulates electric vehicle performance requirements, projects representative future battery characteristics, calculates urban driving range versus total car weight, and estimates energy and material requirements for selected driving ranges.

2. G. M. Houser, Population Projections for the Los Angeles Region, 1980-2000

   Projects population of California's South Coast Air Basin, which includes greater Los Angeles, by county and age group.

3. W. F. Hamilton and G. M. Houser, Transportation Projections for the Los Angeles Region, 1980-2000

   Projects Los Angeles freeway and transit networks, auto population, auto usage, auto size and age distributions, and average fuel consumption.

4. J. Eisenhut, Economic Projections for the Los Angeles Region, 1980-2000

   Projects employment and income for the South Coast Air Basin, and the payroll and employment of businesses involved in production, distribution, and maintenance of automobiles and parts.

5. A. R. Sjovold, Electric Energy Projections for the Los Angeles Region, 1980-2000

   Summarizes the US energy situation as forecast in recent studies, and in this context projects electric energy production and consumption in the South Coast Air Basin, noting energy available for electric car recharging and its basic sources.

Task reports in Volume 3 project impacts due to various levels of electric car use and investigate possible future levels of use, as follows:

6. J. R. Martinez and R. A. Nordsieck, An Approach to the Analysis of the Air Quality Impact of Electric Vehicles

   Selects the "DIFKIN" computer model and linear rollback as means for analyzing future air quality in the South Coast Air Basin, designates important cases for investigation, and details required methodology.

7. J. R. Martinez and R. A. Nordsieck, Air Quality Impacts of Electric Cars in Los Angeles

   Forecasts stationary and vehicular pollutant emissions in spatial and temporal detail, with and without electric cars, and calculates consequent air quality levels relative to Federal standards.

8. A. R. Sjovold, Parametric Energy, Resource, and Noise Impacts of Electric Cars in Los Angeles

   As a function of percentage electric car use, forecasts total energy consumption and petroleum consumption in the South Coast Air Basin through the year 2000; compares annual consumption and rolling inventory of key electric car materials with past and projected US production, consumption, and reserves; analyzes possible reductions of community noise from electric car use.

9. J. C. Eisenhut, J. A. Cattani, and F. J. Markovich, Parametric Economic Impacts of Electric Cars in Los Angeles

Projects life cycle costs of alternative electric cars in comparison with conventional cars; analyzes and projects changes in employment and payroll in industry segments impacted by electric cars, including service stations, battery manufacturing, auto parts and repairs, and auto sales; considers overall regional and national economic impacts of electric cars.

10. W. F. Hamilton, Usage of Electric Cars in the Los Angeles Region, 1980-2000

Analyzes 1967 data to determine distributions of daily driving range in Los Angeles and the applicability of limited-range electric cars; reviews market trends and estimates the potential free-market sales of electric cars in the South Coast Air Basin; hypothesizes particular levels of electric car use for impact evaluations; and considers relative economic incentives likely to be required to obtain these usages.

TASK REPORT 6

AN APPROACH TO THE ANALYSIS OF THE AIR QUALITY IMPACT OF ELECTRIC VEHICLES

J.R. Martinez
R.A. Nordsieck

ABSTRACT

As a part of an overall evaluation of electric vehicles as a transportation alternative, a plan is outlined for quantifying the air quality changes which could be expected to accompany various levels of replacement of conventional automobiles by electrics. The study will focus on California's South Coast Air Basin in the years 1980, 1990, and 2000. The fraction of all vehicle miles which are traveled by electrics, itself a function of such variables as vehicle performance, availability of recharging power, and resource limitations, is selected as the independent variable for the parametric analysis. Baseline pollution levels (ozone, oxides of nitrogen, hydrocarbons, carbon monoxide, particulates, and sulfur dioxide) in the study years will be predicted using the DIFKIN photochemical-diffusion model and the rollback technique. Parallel applications of the DIFKIN model and the rollback technique will predict changes in worst case air quality with varying electric vehicle use in the study area, with particular emphasis on known high pollution locations. Predictions of more typical pollution levels will be based on concentration probability distributions compiled from existing LAAPCD records.

The worst case conditions will be characterized by meteorology measured on a typical high oxidant day in September 1969. A series of time-phased trajectories will be simulated to arrive at selected sites which have regularly exhibited high pollutant concentrations. The effects of increased NO_x emissions due to added power plant demand for battery recharging will be evaluated similarly using air trajectories starting at selected power plant locations. Emissions from vehicular sources are to be calculated from network flow model projections of vehicle miles travelled and estimates of average vehicle emission factors based on vehicle mix, emission control rules, and deterioration effects.

Extrapolations of air pollution control district emissions inventories distributed geographically through land use projections will provide a model of stationary source emissions.

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1 INTRODUCTION

Electric cars have been proposed as a means of alleviating the air pollution problems that afflict urban areas. As one step in evaluating this proposal, this work describes the approach GRC will follow in evaluating the air quality changes likely to occur if significant numbers of electric vehicles replace conventional cars in the South Coast Air Basin (SCAB) of California, which contains Los Angeles County and outlying areas.

The Los Angeles region is probably the best known, and certainly the most studied example of the interactions among air pollution, motor vehicles, and urbanization. With an area of 1250 square miles, it contains more than 7 million inhabitants and more than 4 million motor vehicles. An idea of the relative contribution of motor vehicles to Los Angeles air pollution can be obtained from Table 1.1 which shows the emissions due to motor vehicles in tons per day and as percent of total emissions; motor vehicles are by far the largest emitters of hydrocarbons and nitrogen oxides, the two pollutants responsible for the formation of photochemical oxidants. Stringent new emission controls on motor vehicles are expected to reduce the daily emissions considerably, both in tonnage and as a fraction of the total. However, even with the new controls the

TABLE 1.1

MOTOR VEHICLE EMISSIONS IN THE LOS ANGELES BASIN IN 1970[1]

Type of Emission	Quantity (tons per day)	Percent of Total Emissions of the Same Type
Carbon Monoxide	8960	98%
Reactive Hydrocarbons	1170	85%
Nitrogen Oxides	755	72%
Particulates	55	42%
Sulfur Dioxide	35	14%

hydrocarbon emissions have been projected to start increasing once again around 1985 as projected increases in the car population offset the effects of controls.[1] A partial conversion to nonpolluting electric vehicles might prevent this upturn. Moreover, the recent extension of deadlines for implementing new automobile emission standards makes even more certain that high air pollution levels will prevail in Los Angeles for some time to come. Among the many air pollution control proposals which have been made, the electric car is both a logical and progressive step forward in the search for an air pollution abatement strategy.

Before adopting electric cars as a component of an air pollution control strategy, it is, of course, essential that their impact on air quality be analyzed. Not only do the costs involved demand such an analysis, but, as experience with pollution control has often shown, solving one problem can create another. In short, the interactions among air pollution and its sources must be closely examined; accordingly, this report presents a program designed specifically to investigate the impact of electric vehicles on air quality.

The sections that follow outline and discuss the objectives, and methods of analysis to be used in the subsequent study phase. We describe our approach to simulating air quality in Los Angeles, methods of forecasting emissions from vehicular and stationary sources, the cases to be considered, and the data displays to be employed. Analysis results are reported in Task Report 7.

2 OBJECTIVES AND METHODOLOGY

2.1 OBJECTIVES

The objective of the air quality impact analysis described herein is a quantitative assessment of the probable concentrations of air pollutants to be found in the Los Angeles region if conventional cars were replaced with electric vehicles in varying degrees. Evaluations will be performed for three target years: 1980, 1990, and 2000. For each of these years we seek answers to the following related questions:

- What would be the air pollution levels if no electric cars were used?
- What changes in air quality take place as electric car use increases?
- What is the probable frequency of occurrence of various concentrations of pollutants?

As a corollary to the second question, we may wish to determine the levels of electric car use required to bring air quality levels into compliance with national standards. The methods to be used in answering these questions are discussed below.

2.2 METHODS OF ANALYSIS

2.2.1 General

This section sketches the processes to be used in performing our air quality impact analysis. Subsequent sections discuss the topics introduced here in detail.

Let us begin with a brief explanation of the concepts involved in the analysis. In essence, our goal is to determine/air quality as a function of electric car use for each of three years: 1980, 1990, 2000. The first step is to establish baseline air pollution levels prevailing in those years if no electric cars were used. The techniques to be used in forecasting mobile and stationary source emissions for these years are described in Sec. 5. Electric car use in terms of numbers of vehicle-miles traveled is then varied parametrically following specified constraints.* Varying electric vehicle use alters the baseline emission patterns since doing so is presumed to reduce the use of conventional autos by some commensurate amount. To evaluate air quality these emission patterns must then be related to pollutant concentrations. Linking emissions and air quality is thus the heart of the analysis and is discussed below and in subsequent sections. The results obtained are then used in conjunction with other data to deduce the statistics of the probable frequency of occurrence of various pollutant concentrations. As is evident, this procedure will yield answers to the questions posed at the beginning of this section (Sec. 2.1).

Two different methods will be used to relate source emissions and pollutant concentrations in the atmosphere. One method employs the air quality simulation model developed at GRC, and the second utilizes the so-called rollback formula.

Use of the GRC model is discussed in Sec. 3; the model itself is described briefly in Sec. 3.1 and extensively in Refs. 2 and 3. In simplest terms, the GRC model simulates the complex interactions among emissions, weather, and chemistry to predict the concentrations of air pollutants.

2.2.2 Worst-Case Approach

Recognizing that national air quality standards (cf. Sec. 7) are specified on a worst-case basis, our analysis will focus on determining worst-case pollution levels. An immediate consequence of worst-case analysis is that we can restrict our attention to those areas of the Los Angeles basin presently afflicted with severe pollution conditions. Criteria for identifying such critical locations are discussed in Sec. 3.3.

---

*Typical factors which affect use levels are market forces, availability of materials (e.g., lead), availability of electric generating capacity for recharging batteries, and vehicle characteristics such as range and speed. A comprehensive discussion of these factors is, of course, beyond the scope of this task report.

As we shall see in the next section, worst-case analysis is a simple matter when using the rollback formula. Using the GRC model, however, calls for specifying meteorological conditions which are conducive to high pollutant concentrations. Criteria for specifying the appropriate meterology are described in Sec. 3.4.

2.2.3 The Rollback Equation

In contrast to the GRC model, the rollback model assumes that pollutant concentrations and emissions are proportional. The formula used is

$$R = \frac{(PAQ) - (DAQ)}{(PAQ) - (B)} \qquad (2.1)$$

where R = fractional reduction in emissions
PAQ = present air quality
DAQ = desired air quality
B = background concentration of pollutant

Thus the rollback formula purports to yield the reduction in emissions required to achieve the desired air quality, e.g., the air quality standard, given the current air quality and the background level of the pollutant, i.e., the concentration unavoidably present due to natural causes.

It should be noted that, since the air quality standards are set on a worst-case basis, a worst-case approach is implicit in using the rollback formula with the air quality standard as the desired air quality. Thus, for the present air quality (PAQ) we must use the highest concentration recorded in the region during the period of interest.

Extreme caution is necessary in using the rollback equation to relate emissions and air quality. While the rollback approximation may fit some cases [e.g., carbon monoxide (CO)], its use for relating emissions and secondary pollutants such as nitrogen dioxide (NO_2) and ozone (O_3) is highly questionable since these two pollutants are produced by chemical processes which are highly nonlinear. The use of Eq. 2.1 is also suspect even with highly reactive primary pollutants such as reactive hydrocarbons (HC) and nitric oxide (NO).

An example of the use of the rollback equation is found in Ref. 4, which describes the formulation of an abatement strategy for Los Angeles designed to reduce ozone levels. Reference 5 contains an evaluation of the ozone changes produced by the cutback in hydrocarbon emissions predicted by rollback. One important finding of this evaluation is that under certain circumstances rollback predicts emissions reductions that are greater than necessary to satisfy the ambient air quality standard for oxidant. Additional discussion regarding the inception and use of rollback is found in Ref. 6.

Since our aim is to determine the desired air quality (DAQ) levels given a present air quality (PAQ), the background level (B), and the fractional reduction in emissions (R), we must solve for DAQ in Eq. 2.1, which yields

$$DAQ = PAQ(1 - R) + RB \tag{2.2}$$

In using Eq. 2.2 the factor PAQ would be the baseline air quality level with no electric car use. The factor R would be determined by the emissions reduction caused by the increasing use of electric vehicles.

One difficulty in using Eq. 2.2 is that the baseline air quality (PAQ) for 1980, 1990, and 2000 is not readily available. Two approaches may be followed to circumvent this problem. The first is to predict the baseline air quality by means of Eq. 2.2 itself. This would be done by using for PAQ , the known air quality for a previous year such as 1969, and estimating R from

$$R = 1 - \frac{E_k}{E_{1969}} \quad ; \quad k = 1980, 1990, 2000$$

where E_k are the baseline emissions for the year k . There is an obvious danger in using this approach, for the gross approximations inherent in the rollback formula may yield anomalous air quality levels. The second approach is to use the values the GRC model predicts as the baseline air quality levels for 1980, 1990, and 2000. This has the advantage of providing a common starting point for the air quality impact analysis for both the GRC model and the rollback formula. Which approach is better will be determined in Task Report 7.

Since the assumptions underlying these two methods are poles apart, predicting concentrations with the rollback approach and the GRC model would yield results which cannot be readily compared. It is therefore difficult to delineate criteria for comparing the results obtained by the two methods in advance, and thus we must await the results of the computations before making any statements about any differences which occur.

2.2.4 Estimation of Overall Air Quality by Statistical Analysis

Worst-case analysis yields information about pollution levels with respect to air quality standards. Thus we can tell whether or not the air quality complies with the standard. Unfortunately, this type of analysis does not tell us much about the general quality of the air the rest of the time. A scheme is described below which can provide such information in the form of frequency of occurrence of various pollution levels.

We wish to use the results of the worst-case air quality predictions together with additional statistical data to deduce how often certain pollution levels may occur. Such information allows us to make judgments, within some reasonable limits of course, regarding the overall quality of the air in the region under study.

The details of the procedure used for deriving statistical information from worst-case results are given in the Appendix. The essence of the process is as follows. We need to find a probability distribution which passes through the worst-case concentrations that have been previously computed. In order to do this we must determine the type and the parameters of the distribution. The work of Larsen[7,8] may allow us to assume that the hourly-average concentrations with which we will be dealing are distributed lognormally. The lognormal distribution is completely defined by two parameters, of which the worst-case concentration is one. The second parameter is the standard deviation, which is obtained from actual concentration data for various pollutants. Larsen[7-9] has tabulated values of the standard deviation for various cities and pollutants; Ref. 9 contains extensive data for California. In addition, we will process tapes of concentration data from the Los Angeles County Air Pollution Control District (LAAPCD) in order to obtain updated estimates of the standard deviation, since Larsen's work stops with 1968. This will also let us test whether Larsen's results can be used. In any event, the standard deviation can be estimated independently and this, together with the worst-case concentrations, completes the definition of the distribution function. Having the distribution function allows us to determine the the probability of occurrence of a given pollution level.

Obviously, the above procedure must be used with caution, to say the least. Interpretation of the results must be guided by the judicious application of bounding criteria to the derived probabilities. Also, it is well to mention at this point that part of Larsen's work has recently come under some justified criticism.[10] However, this has no bearing on the process just described since we do not use that part of Larsen's work. It should be noted that Larsen's findings about the lognormal distribution of pollutant concentrations have recently received independent support.[11,12]

2.2.5 Summary

The process followed in the analysis of the air quality impact of electric vehicles is illustrated in Fig. 2.1; the figure is self-explanatory.

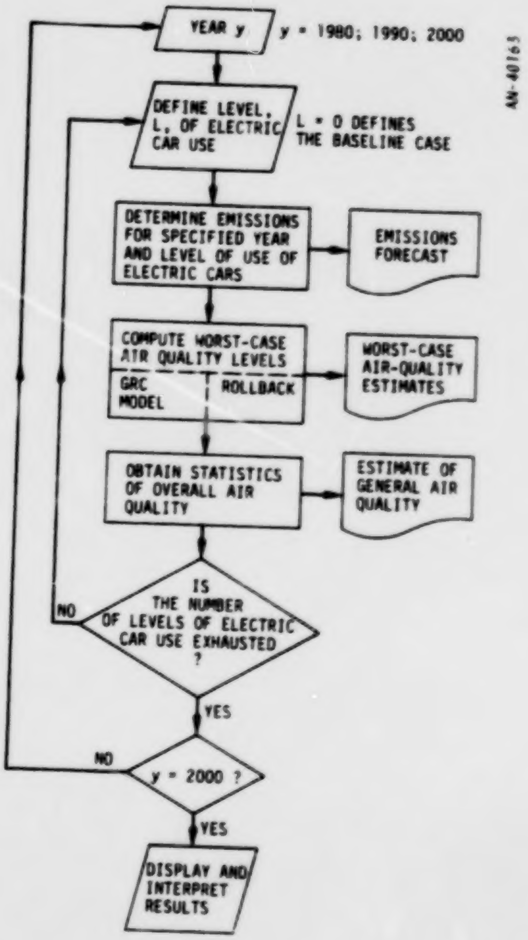
YEAR y
y = 1980; 1990; 2000
AN-40163
DEFINE LEVEL, L, OF ELECTRIC CAR USE
L = 0 DEFINES THE BASELINE CASE
DETERMINE EMISSIONS FOR SPECIFIED YEAR AND LEVEL OF USE OF ELECTRIC CARS
EMISSIONS FORECAST
COMPUTE WORST-CASE AIR QUALITY LEVELS
GRC MODEL
ROLLBACK
WORST-CASE AIR-QUALITY ESTIMATES
OBTAIN STATISTICS OF OVERALL AIR QUALITY
ESTIMATE OF GENERAL AIR QUALITY
IS THE NUMBER OF LEVELS OF ELECTRIC CAR USE EXHAUSTED ?
NO
YES
y = 2000 ?
NO
YES
DISPLAY AND INTERPRET RESULTS

Figure 2.1. Flow Chart of Major Steps in Air Quality Impact Analysis

3 SIMULATION OF AIR QUALITY USING THE GRC MODEL

3.1 OVERVIEW OF THE GRC MODEL[2,3]

The model developed by GRC for simulating photochemical smog employs a trajectory-oriented, moving-coordinate-system approach. Figure 3.1 is a diagram of the concepts used in the model. An air parcel moves along a path determined by the local prevailing wind speed and direction at various times during the day. The air parcel is divided vertically into a mesh of equally spaced points. As the air parcel moves over a region it receives pollutant emissions from the ground. The pollutants within the air parcel then undergo chemical reactions and diffusion, with the incident sunlight driving several of the chemical reactions that occur. At each mesh point, the concentrations of several species of pollutants are computed: NO, NO_2, hydrocarbons, and ozone, to name a few. The output of the program consists of the species concentrations as functions of time and height.

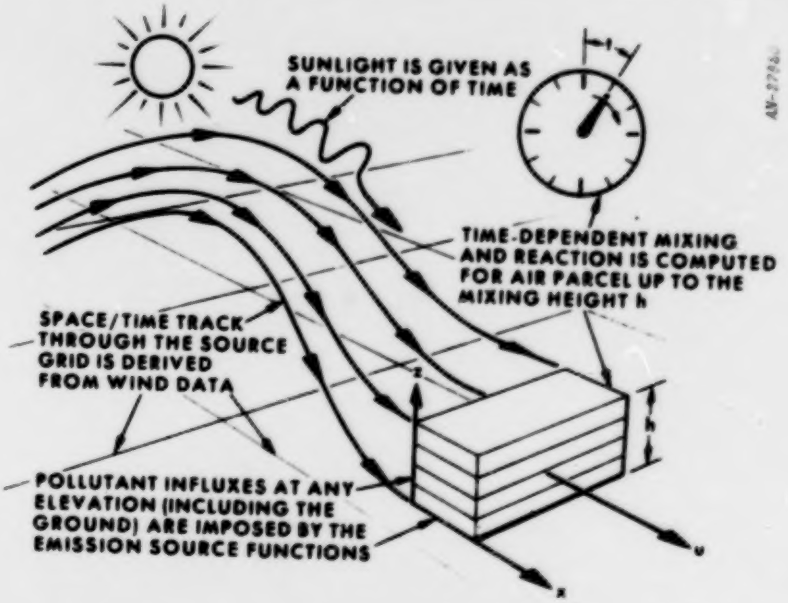
SUNLIGHT IS GIVEN AS A FUNCTION OF TIME
t
TIME-DEPENDENT MIXING AND REACTION IS COMPUTED FOR AIR PARCEL UP TO THE MIXING HEIGHT h
SPACE/TIME TRACK THROUGH THE SOURCE GRID IS DERIVED FROM WIND DATA
z
h
POLLUTANT INFLUXES AT ANY ELEVATION (INCLUDING THE GROUND) ARE IMPOSED BY THE EMISSION SOURCE FUNCTIONS
u
x

Figure 3.1. Schematic GRC Photochemical Diffusion Model for Air Quality Simulation

The model thus consists of three parts. One part computes the trajectory followed by the air mass; another determines the emissions that enter the air parcel as it sweeps over the region; the third part combines emissions, dispersion, and chemistry to calculate the concentrations of the pollutants along the trajectory.

A key component of the model is the chemical submodel. The GRC chemical model has been extensively documented in Ref. 3. Briefly, it contains 16 reactions and nine chemical species. The photochemical pollutants of interest in air quality standards are represented: nitrogen oxides, hydrocarbons, and photochemical oxidants, e.g., ozone. Reactions involving particles are treated in a lumped-parameter fashion. The air quality simulation model also computes the concentration of species, such as carbon monoxide, which are regarded as chemically inert.

The model also has provisions for dealing with elevated sources such as power-plant stacks. Stack heights and locations can be provided as inputs, with the emissions inserted at the appropriate height in the air parcel when the parcel sweeps over the stack.

Summarizing, the GRC model combines chemistry, emissions, and meteorology to simulate the complex interactions of a multicomponent mixture of pollutant species. The results are the concentrations of the various pollutants as functions of time and height.

3.2 CONSIDERATIONS IN AIR QUALITY MODELING

In assessing the air quality impact of electric vehicles using the GRC model, we will first select several critical locations in the Los Angeles basin which are known to be afflicted by high levels of air pollution. The chosen locations and the criteria used in the selection are discussed in Sec. 3.3.

Having designated the target areas (receptors), air trajectories will then be obtained which arrive at the specified locations at various times of the day when contaminant levels are expected to be high. For example, in downtown Los Angeles peak oxidant readings generally occur around noon, whereas CO maxima coincide with the traffic peak and thus occur early in the morning. In this manner we obtain the pollutant levels as functions of time at each selected location and also along the path of the trajectory.

Several trajectories per receptor will be computed, with each of the several trajectories per location arriving at a different time. The total time interval covered is chosen so that it contains the time when the highest pollution levels are expected. Because of the geographical dispersion of the receptors, the trajectories will be chosen so that they cover nearly the whole Los Angeles basin, thus allowing us to obtain pollution levels on a regional scale. In addition, the emission patterns sensed by the trajectories will contain a wide variety of mobile and stationary sources. This ensures that the model is sensitive to changes in source strengths. Section 3.4 contains additional information regarding the determination of the trajectories.

The meteorological data used to compute the trajectories and to define atmospheric dispersion parameters are data that were taken in Los Angeles during the Period August-October 1969. During that period a special monitoring program[13] was performed in Los Angeles which included very refined inversion base soundings using aircraft at various times of day. Such data are not available for any other time. Also, our model validation studies[3] were conducted using the same 1969 data and this tends to strengthen the confidence in the results obtained. Nevertheless, since we are following a worst-case approach the question may be raised whether 1969 is indeed representative of the worst year. Examination of the statistics of pollution concentration in Ref. 1 for the period 1966-1970 reveals that the frequency of occurrence of high ozone concentrations is remarkably stable throughout this period. Furthermore, although four alerts[*] were called in 1969 and 1970 had nine alerts, the largest number in five years, during August-October 1970 there were only five alerts whereas all four 1969 alerts took place during August-October. In fact, as is shown in Table 3.1, the August-October statistics for 1969 and 1970 are hardly distinguishable. Thus the available data indicate that this period of 1969 is comparable to that of any other year during 1966-1970 and it seems satisfactory to use 1969 meteorological data for our computations.

Under EPA sponsorship we have recently completed an extensive controlled evaluation of the model by comparing predicted and measured pollutant concentrations. The results of the evaluation are reported in Ref. 3. The testing procedure involved using six days of air quality data obtained in Los Angeles in 1969. The data for three of the days

TABLE 3.1[*]

AUGUST-OCTOBER STATISTICS FOR 1969 AND 1970

	1969	1970
Number of alerts	4	5
Number of days with eye irritation	65	57
Number of days on which oxidant > 0.1 ppm hourly average[**]	88	84
Number of days on which $NO_2 \geq 0.25$ ppm hourly average[**]	41	40
Number of days on which $CO \geq 10$ ppm for 12 hours[**]	50	52

[*] Reference 1.

[**] California state standard in force in 1970.

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[*] LAAPCD first alert level for ozone is 0.5 ppm for five minutes.

were used to adjust the model's parameters and to develop rules for operating the model in a so-called "hands-off" mode. The remaining three days were then modeled using the "hands-off" rules. These rules will also be applied when using the model to perform the air quality impact analysis. Because of the extensive model validation tests that have been carried out, we believe that it is not necessary to conduct additional testing other than the usual shakedown runs required by any model.

As is the case with any model, in order to obtain meaningful results care must be taken to ensure that the model is not exercised beyond the limits imposed by the data base used to validate the model. However, we note that the data base used in our validation studies[3] contained a large assortment of source strengths and pollutant concentrations and this reduces the chance of operating the model outside its validation range in the course of the study. In any event, should the occasion arise, special procedures will be used to prevent the occurrence of such a situation.

Summarizing, the procedure followed in using the GRC model to evaluate the air quality impact of electric vehicles consists of four subtasks:

1. Selection of critical locations in the Los Angeles basin
2. Identification of worst-case meteorology
3. Determination and selection of air trajectories
4. Computation of pollutant concentrations

The first three of these subtasks are discussed below.

3.3 SELECTION OF CRITICAL SITES

We have chosen to focus our attention on a few selected sites in the region because of our interest in worst-case air quality conditions, a desire to be realistic in our assessments, and in the interest of economy of operation. However, let us note that concentrating on key locations does not prevent us from estimating air quality on a regional scale. The reason is that the selected sites are the terminal points, the receptors, of the air trajectories and that pollution levels are computed along the trajectory's path. The criteria, described below, used in the selection of the receptors ensure that the trajectories will thoroughly cover the region of interest.

The criteria used in selecting the key sites are:

- Prevalence of high pollution levels
- Geographical dispersion
- The position of the site with respect to the prevailing flow patterns

In order to satisfy the first criterion, air quality monitoring data provided by local Air Pollution Control Districts were used to guide the site selection process. Because of the peculiarities of the geographical distribution of the various types of source and the different chemical characteristics of the pollutants of interest, the application of the first criterion will require that the selected sites be matched to specific pollutants. Thus all the sites cannot be expected to be equally suitable for determining worst-case levels for all pollutants.

Oxidant levels are of special concern in site selection since recent abatement strategies proposed for Los Angeles by EPA have been aimed at reducing oxidant concentrations.[4] Hence some sites must be selected on the basis of their high oxidant readings. This requirement implies that some sites will be located on the eastern part of the Los Angeles basin since the highest oxidant concentrations are known to occur there.

In contrast to oxidant, high levels of nitrogen oxides (NO_x), CO, and HC are more likely to occur close to the sources and we must turn to the densely populated central basin to select the appropriate sites. Large concentrations of sulfur dioxide (SO_2) will also be found in the vicinity of sources. In Los Angeles the highest SO_2 levels occur near the coast where the power plants and oil refineries are concentrated.

The sites should be geographically dispersed in order to obtain pollution estimates on a regional scale. However, the first and third criteria may impose restrictions on the geographical dispersion. Wide spatial separation between sites is also desirable because the air in the trajectories is thus exposed to a large variety of source configurations.

The Los Angeles basin possesses a distinct pattern of air flows during the smog season. In general, the air flows from west to east during the day and reverses its flow at night, thus creating a so-called "sloshing" action. Accordingly, the daytime flow of air makes the pollutant concentrations in the eastern basin be functions of the emissions produced in the western and central parts of the region. This is especially true of ozone levels because the pollutants react to produce ozone while on their way to the east basin. In addition, topographical features such as mountains and canyons contribute to creating distinct pathways through which air flows preferentially. Because of this guideway effect certain downwind locations will bear the brunt of the heavy emissions produced in such central basin areas as downtown Los Angeles. This phenomenon has also been termed the "pipe reactor" effect.[14]

Recognizing the existence of the flow patterns described above, the third criterion calls for locating the selected sites on the path of the prevailing winds. This is consistent with our worst-case approach. In this manner the computation of secondary pollutants, NO_2 and O_3, is made sensitive to changes in emissions which occur elsewhere in the basin. It should be noted that the LAAPCD has located monitoring stations along the path of the prevailing flows.

Five sites have been selected following the criteria described above. Data about the statistics of pollution levels at various sites were examined and compared in order to ensure that the first criterion is satisfied. Table 3.2 lists the five sites together with the pollutants which are most significant at each location. Figure 3.2 shows a map of the region which illustrates the geographical distribution of the selected sites. Also shown in Fig. 3.2 is a typical afternoon pattern of wind flows in order to enable the reader to see the relationship between site location and the flow pattern.

A few comments should be made about the selections. First of all, we note that only one site has been chosen for estimating SO_2 effects. Los Angeles has a very stringent program for controlling sulfur emissions and SO_2 concentrations become significant at very few places. Long Beach generally experiences the highest SO_2 concentrations. (See also Sec. 4.1 for further remarks on the treatment of SO_2.) Because of its coastal location, Long Beach is not as heavily afflicted with other pollutants as other points in the region.

TABLE 3.2

SELECTED LOCATIONS IN THE LOS ANGELES AIR QUALITY CONTROL REGION AND MOST SIGNIFICANT POLLUTANTS AT EACH SITE

	Pollutant					
Site	O_3	NO_x	HC	CO	Particulates	SO_2
Downtown Los Angeles		X	X	X	X	
Azusa	X	X			X	
Long Beach						X
Riverside	X	X				
Anaheim	X	X			X	

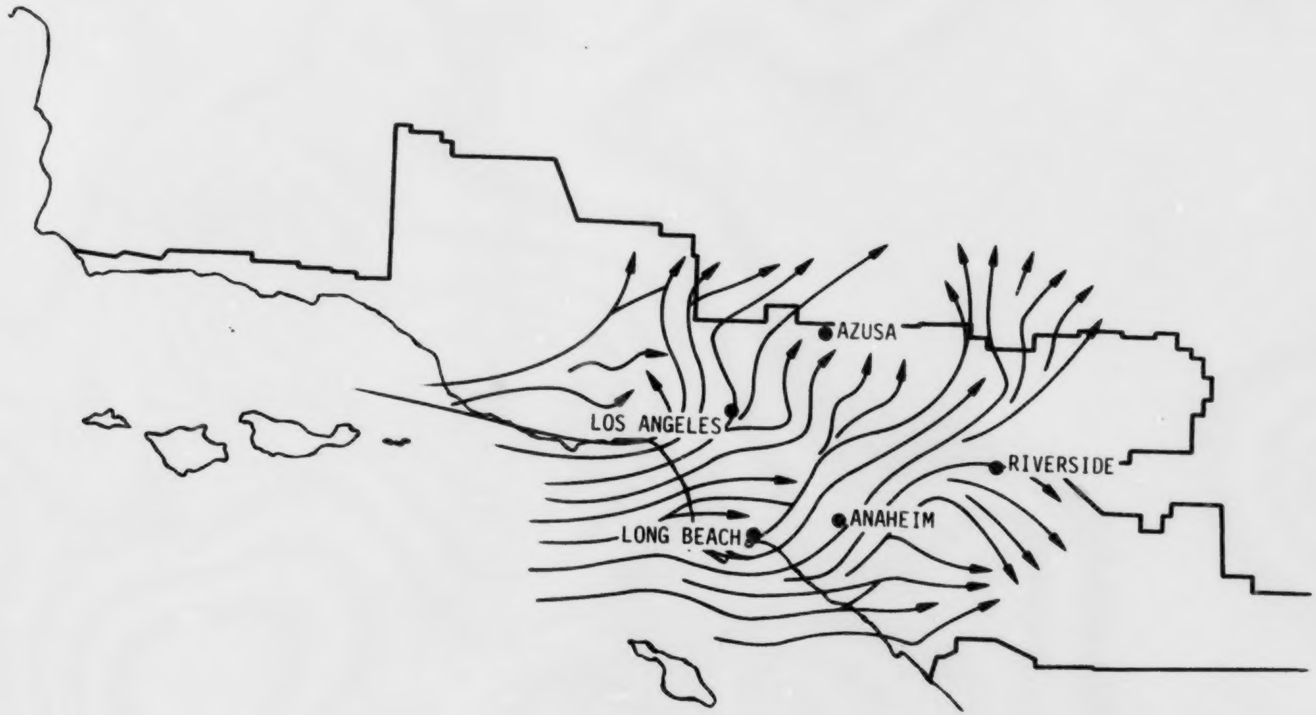
AZUSA
LOS ANGELES
RIVERSIDE
ANAHEIM
LONG BEACH

Figure 3.2. Map of South Coast Air Basin Showing Critical Sites and a Typical Autumn Afternoon Flow Pattern

Four of the five stations, Long Beach excepted, experience either high or medium levels of ozone. Riverside is well known for the peak hourly average of 0.62 ppm which occurred in 1970 and which formed the basis of the EPA abatement strategy already mentioned.[4] Azusa consistently records ozone levels which exceed the standard of 0.08 ppm hourly average and about 30 percent of the daily maximum hourly readings are in excess of 0.20 ppm.[14] Anaheim also is afflicted by high oxidant levels during the smog season. Downtown Los Angeles, on the other hand, registers mostly medium and low levels of ozone, with 0.19 ppm daily maximum hourly average concentration exceeded less than 10 percent of the time. In fact, ozone levels in downtown Los Angeles have been shown to be following a trend toward lower values over the last six years.[14] Thus Downtown Los Angeles is not important as far as oxidant is concerned. However, because of the large number of sources present in the vicinity of Downtown Los Angeles, we can expect this location to have high concentrations of NO_x, HC, CO, and particulate matter.

Azusa is located on the eastern edge of the basin, at the end of the "reactor pipeline." By Los Angeles standards, the population density around Azusa is relatively low, so we do not expect to see high concentrations of CO and HC. Particulate matter concentrations tend to be high because of the formation of aerosols by chemical processes. Levels of NO_2 also are high because the air masses arriving at Azusa have had enough time to perform the chemical conversion of NO to NO_2. However, analysis of concentration data for Azusa has shown that NO_x levels are not as high as in downtown. This is not surprising inasmuch as downtown NO_x consists mostly of NO whereas at Azusa NO_2 is the main constituent. Since NO_2 is the more toxic component of NO_x, we shall be interested in NO_x at Azusa.

Riverside, like Azusa, is also the recipient of pollutants transported from Los Angeles and thus is at the end of another "reactor pipeline." Accordingly, it has a high incidence of large oxidant levels as well as NO_x. Anaheim has high concentrations of ozone and NO_x and, in addition, consistently records high readings of particulate matter.

3.4 IDENTIFICATION OF WORST-CASE METEOROLOGY

In general, the meteorological conditions which lead to high contaminant concentrations consist of a hot day with low wind speeds and a strong temperature inversion. The emissions are trapped by the inversion and the poor dilution capability of the atmosphere thus results in high pollution levels. When such conditions exist the atmosphere is said to be stable.

The worst case occurs when the atmosphere remains stable for several days in a row. Very high pollutant concentrations then occur due to the extended accumulation of contaminants. The longest episode of this kind occurred in Los Angeles in July 1955, when high ozone levels persisted for twelve days.[15] As might be expected, single-day episodes are far more common. For example, from 1956 to 1971 there were 213 days when the maximum hourly ozone level equaled or exceeded 0.40 ppm. Of these 213 days, 103 were single-day episodes.[15]

We wish to be realistic in the choice of meteorological conditions for modeling purposes. The proposed approach is to use the meteorology that prevailed during a single-day episode since the atmospheric conditions on such a day are typical of the worst that may be encountered. In addition, we require that weather and aerometric data of high quality be available in order to provide reliable inputs to the model.

The day of September 29, 1969, satisfies the conditions mentioned above. Accordingly, it has been selected as the prototype day for the worst-case predictions of pollutant levels. Heavy eye irritation was recorded in Los Angeles on September 29, and an ozone first-level alert was called on this day (see p. 6-13 for a definition of alert levels).[15] Moreover, and not coincidentally, extensive records of meteorological data are available for this day as a result of a special experimental program carried out by Scott Research Laboratories.[13] These data include frequent aircraft soundings which delineate the height of the inversion layer. For this day, the profiles of atmospheric temperature indicate a very stable atmosphere during the hours 0600-0800 PST, with subsequent changes to stable and neutral conditions as the day warms up. The inversion was ground-based in the early morning hours and subsequently lifted to about 1000 feet above sea level at noon and thereafter as the result of solar heating. Finally, it should be noted that precisely because of the properties already mentioned, September 29 was also used as one of the days for which our model was calibrated during the model validation tests.[3] The experience with September 29, 1969 accumulated in the validation process will facilitate our modeling task and enhance confidence in the results.

3.5 SELECTION OF TRAJECTORIES

In selecting the trajectories, the following guidelines have been used. First, the trajectories must fan out in such a manner as to cover a large territory. This allows us to obtain regional-scale estimates of pollution levels. Second, the arrival times at the destination must encompass the expected time of occurrence of the maximum concentration of the pollutant of interest. Third, the trajectory must be long enough so that it will have a high ratio of mass received from emission sources to the initial mass. This criterion ensures that the computed concentrations will be sensitive to changes in emissions, a most important requirement in our work. Fourth, we want to have trajectories which have very low initial concentrations of the various species, especially HC, NO, and NO_2. This calls for starting the trajectories during the early morning hours, preferably before dawn, when pollution levels tend to be low. It is apparent that the third and fourth guidelines are related since having a small initial mass of pollutants will enhance the sensitivity to source emissions. We also note that since the starting point of a trajectory is generally not going to be in the vicinity of a monitoring station, the initial conditions are likely to be inaccurately known. Hence it is important to reduce as much as possible the model's sensitivity to initial concentrations.

Meteorological data measured at various monitoring stations on September 29, 1969, will be used to obtain the trajectories which will be computed using the trajectory-generation program which is an integral part of the GRC simulation model. To illustrate, one of the trajectories to be used in the study is shown in Fig. 3.3. The trajectory begins over the ocean at 0100 and arrives at Anaheim at 1300, its nodes being spaced at hourly intervals. This trajectory is receptor-oriented since it arrives at a given point (Anaheim) at a designated time (1300). In addition to receptor-oriented trajectories, we will use some trajectories which originate at a specified point in order to test the effects of increased emissions of power plants; such trajectories are said to be source-oriented. All the trajectories used in the study will be shown in the companion report which contains the results of the air quality predictions.

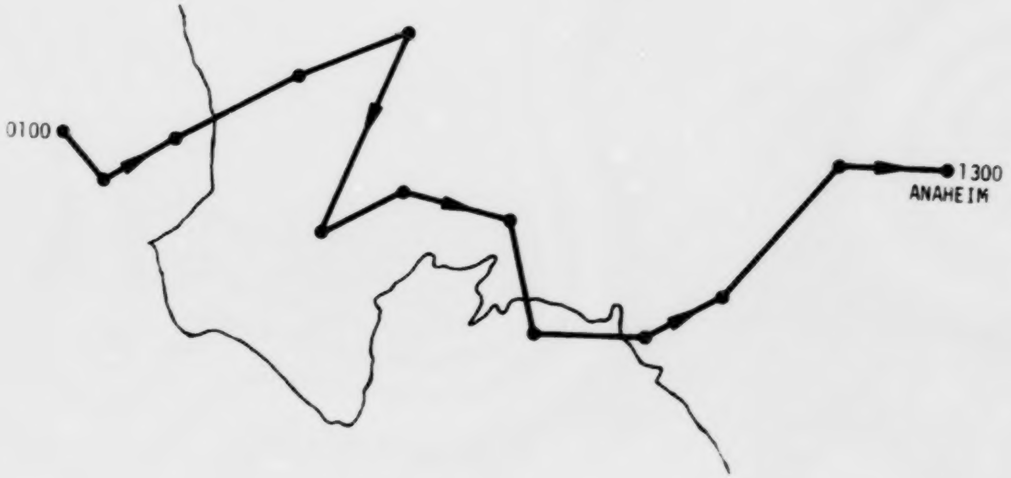

Figure 3.3. Trajectory for September 29, 1969, Which Arrives at Anaheim at 1300

4 FACTORS AFFECTING AIR QUALITY IMPACT OF ELECTRIC VEHICLES

In this section we discuss the treatment of several factors which are specially significant in determining the air quality impact of electric vehicles.

4.1 EFFECT OF ELECTRIC CARS ON EMISSIONS FROM STATIONARY SOURCES

With respect to stationary sources, the major impact of electric vehicles will be on power plant emissions by virtue of the increased power demand created by battery recharging. Several questions arise in this context:

- How much new generation will be required for various levels of electric car use?
- Will nuclear or fossil-fueled plants be used to satisfy the increased demand?
- To the extent that present and/or future fossil-fueled plants are used to provide power for electric cars, what effect will this have on emissions and hence air quality?

The answer to the first question is beyond the scope of this report; this information will be developed in a separate study task. Nevertheless, proceeding on the assumption that some amount of new generation will be required, we can discuss qualitatively the likely air quality impacts associated with the second and third questions.

The second question goes straight to the heart of the matter. For it is clear that air pollution from stationary sources will be profoundly affected by a decision in favor of either type of plant: nuclear or fossil-fueled. Obviously, any answer to this question involves judgments which may, and probably will, be modified by future events and should be judged in this light.

Discussions with public officials and perusal of the literature reveal the following scenario. Over the short term, until about 1990, nuclear units are not expected to provide a large fraction of the total generating capacity in Los Angeles. For example, a study by Stanford Research Institute[16] for all of Southern California, not just Los Angeles, projects nuclear generating capacity at 11 percent of the total in 1980, 35 percent in 1990, and 71 percent in 2000. It is expected that the expansion of conventional thermal generating capacity will be accomplished by the addition of topping units, mostly gas turbines, to existing plants. Thus conventional thermal units, i.e., gas- and oil-fired, will be the mainstay in power generation for 1980 and 1990, and will still be very much in evidence in 2000. A separate task of the study will provide detailed information about fossil-fueled plant locations and capacities.

Going on to the third question, it is apparent from the previous discussion that a major effect of using electric vehicles would be to shift emissions from mobile sources to power plants. It should be noted that the character of the emissions will change since power plants emit mostly NO_x and SO_2 and only very minimal amounts of hydrocarbons. Thus there would be a marked overall reduction in hydrocarbon emissions and a lesser degree of improvement in NO_x emissions; there could be an increase in SO_2 emissions unless special measures are taken to prevent it. Stricter controls must also be placed on the emission of particulates from power plants, lest we see an increase in such emissions. It should be noted, however, that the published inventory for Los Angeles shows that power plants account for only 4 percent of particulate emissions.[1] The reduction in hydrocarbon emissions is likely to be very important in terms of controlling the formation of photochemical oxidants. The net effect of the shift to power plants could be an overall reduction in emissions since stationary sources are generally easier to control than cars.

Because of a shortage of low-sulphur fuels, i.e., oil and gas, the prognosis for the next several years is for an increase in the use of high-sulphur fuels for power generation in the Los Angeles Basin. This implies, of course, increased SO_2 emissions unless more stringent emission controls are placed on the stationary sources. However, it is expected that this problem is of a short-term nature, lasting only until 1976 or 1977. By 1980, the expectation is that control technology together with the use of low sulphur oil may keep SO_2 emissions per unit of generated power to low levels.

However, increases in power generation may result in an overall increase in total SO_2 emissions from power plants. Emissions of nitrogen oxides from power plants may still be substantial by 1980 and beyond. Hence, localized effects at receptors downwind of the power plants must be investigated. Since, as is noted in Sec. 5, expansions in generating capacity are expected to consist of additions to present plants within the L.A. Basin, we can use air trajectories which sweep over some known plants to determine the incremental effects on air quality.

A way to meet the increased power demand is to recharge electric vehicles using existing generating capacity, with increased power generation during off-peak periods. This has the effect of leveling the peaks and valleys of the power plant operating curve, mainly by raising the level of the valleys. As a result, nighttime emissions will be increased. When stagnant conditions prevail at night, a condition which we have assumed to exist in the course of our worst-case analysis, the increased NO_x emissions will tend to accumulate over the region since chemical activity is very low at night. The early-morning pollutant load of nitrogen oxides is thus increased and this will affect the formation of photochemical oxidants later in the day. However, whether more or less oxidant is formed is open to question since the reduced hydrocarbon load may tend to balance out the increase in NO_x. In fact, low HC/NO_x ratios in the atmosphere inhibit the formation of oxidants. Such effects will be included in the simulation, especially since we have made an effort to select trajectories which originate at night.

As a final note, we wish to point out that many of the judgments and speculations mentioned above regarding the availability of fuels need to be placed in the context of the current energy crisis. A thorough evaluation of the fuel situation is being conducted separately and its results, when available, may indicate the need to modify some of our statements and proposed approaches.

4.2 PUBLIC POLICIES AND ELECTRIC VEHICLE USE

The implementation of certain policies by legislative or executive mandate may produce significant changes in the air quality panorama of the future. For example, policies may be promulgated that will encourage the use of electric vehicles at the expense of conventional autos. Conversely, other policies may point in the direction of improved air quality with conventional cars and this could have the effect of reducing to insignificance the contribution of electrics towards cleaner air.

In this section we examine several policies which have been proposed by EPA to reduce air pollution in Los Angeles.[24] Variations of these policies have been suggested for application to many other cities across the country. The intent of our review is to evaluate the effect of the policy vis-a-vis electric car use and to explain how such eventualities are treated in our study.

Broadly speaking, the proposed policies fall in the category of transportation controls whose aim is to reduce the number of automobile miles traveled. The main provisions of the policies are:

1. Parking restrictions in the central business district.
2. Incentives for the use of busses and car pools.

In addition to the transportation controls, the policies aim to reduce emissions by

1. Establishing an annual inspection system for private cars and light trucks to ensure that emission control devices work properly.

2. Retrofitting 1966-1974 model cars with oxidizing catalytic converters to reduce HC and CO emissions.

The plans also envision providing incentives for the eventual construction of a mass transit system for the area. Notably absent from the first phase of the policies is the requirement for gasoline rationing which had been previously advanced.[4] However, the EPA announcement states that gasoline rationing may be put in effect by 1977 if expected improvements in air quality do not materialize by then.

The transportation controls for Los Angeles, without gas rationing, are expected to reduce the number of vehicle-miles traveled from a minimum of 14 percent to a maximum of 43 percent.

Several of the proposed transportation controls have been the subject of a recent study at GRC.[17] Two of the strategies studied which are most relevant to this discussion are a strategy which would reduce vehicle-miles traveled by 30 percent uniformly across the L.A. Basin and another which would reduce the number of vehicle-miles by 90 percent in a 60-square-mile area around the central business district. The first case clearly falls within the range of the expected reductions in vehicle-miles. The second case ties in with the proposed parking restrictions in the central business district.

The results obtained for the 30-percent reduction indicate marginal improvements in air quality. However, we note that greater leverage might be achieved with a 30-percent reduction in vehicle-miles in the presence of more stringent stationary source controls; this might well be the case in 1980 and beyond. Thus, such a policy could have the effect of promoting enthusiasm for electric cars as a way of reducing the inconvenience to people who wish to move about at will. Admittedly, other considerations such as reduction of congestion may work in favor of an absolute reduction in the number of cars on the road, but this is beyond our ken at this time.

The strategy which would reduce all traffic by 90 percent in the downtown area can have significant beneficial air quality effects, but only in localized areas and under special circumstances. This is not surprising upon recognizing that the area of 60 square miles is imbedded in a larger region of 1250 square miles. Thus the sphere of influence of the central business district is likely to be small. Furthermore, only those localities which lie downwind of the central business district will be affected and the effect will thus be randomly distributed since it is a function of the wind direction and speed, themselves random quantities. In sum, such a strategy could have some beneficial results, but the effects will be spread over a relatively small area.

It is possible that the imposition of any kind of transportation controls on conventional cars, such as those mentioned above, may induce people to gravitate toward electrics. This would, of course, increase the level of use of electric cars with a concomitant improvement in air quality. One way to quantify this is to vary the level of use of electric cars within the 14-to-43 percent expected reduction in the number of vehicle-miles traveled by conventional cars.

Establishment of a mass transit system in Los Angeles would have the effect of reducing the number of individual cars on the road, thereby cutting pollution. However, the timing for implementation is unclear at this time inasmuch as financing difficulties abound.* Furthermore, it is an open question whether, in the absence of other inducements or restrictions, significant effects will materialize. In this respect, discussions with personnel of the Southern California Rapid Transit District regarding a proposed multibillion dollar mass transit system indicate that even under the most optimistic assumptions the most that can be expected is a 10% reduction in the number of vehicle-miles traveled by 1990. Unless a greater impact is achieved, it appears that a mass transit system for

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*After this was written, Los Angeles residents rejected a 1-percent increase in the sales tax earmarked for mass transit at an election in November 1974, thereby essentially killing the program.

Los Angeles will not by itself achieve significant gains from an air pollution standpoint.

Another kind of public policy which will have a profound effect on the air quality impact of electric cars is the policy which defines and enforces emission standards for heat-engine-powered cars. Even though strict standards have been imposed on future cars, uncertainty exists regarding enforcement and even the standards themselves. One reason for this state of affairs is that basic scientific knowledge is lacking in several important areas. Auto manufacturers have been granted extensions of the implementation deadlines and the possibility exists that the NO_x emission standard may be relaxed. However, should the promise of significant emissions reductions materialize, then by 1980 and beyond we would have a situation in which electrics would replace low-pollution cars. The beneficial impact of electrics from an air quality standpoint would then be diminished. Quantifying such an effect involves manipulating the age distribution of automobiles in establishing the baseline emission factors. For a given year, the lower bound is determined by assuming that all the cars are current-year models. This would produce the lowest possible level of automotive emissions. Such an assumption is admittedly unrealistic and other perturbations of the age distribution may yield more credible results. The section on forecasting baseline emissions (Sec. 5) describes the procedures that are followed in establishing bounds for such eventualities.

Another situation in which electrics would compete with relatively low-pollution conventional vehicles arises out of the requirements for an annual inspection/maintenance and catalytic converter retrofit program for 1966-1974 vehicles. A recent study by J. Horowitz[25] of EPA claims reductions of 8 percent in HC emissions and 10 percent in CO emissions for the total car population by instituting an inspection/maintenance program for pre-1975 vehicles. These reductions would apply until about 1980 and would decrease to about 2-to-3 percent by 1985 because of the turnover in the car population. Much higher claims are made by the same author[26] for the retrofit program of installing oxidizing catalytic converters combined with an annual inspection/maintenance schedule. In this case potential reductions range from 30 to 50 percent by 1980 and decrease to 10 to 20 percent by 1985, depending on the pollutant. The retrofit proposal thus offers the possibility of substantial gains, but at a relatively high cost to the consumer. For purposes of our study we will estimate realistic bounds for the expected reductions in emissions from conventional cars. We then plan to consider such a scenario explicitly as a special case.

5 FORECASTING OF POLLUTANT EMISSIONS

5.1 OVERVIEW

The task of predicting pollutant emission patterns for our analysis of potential electric car impact in the years 1980, 1990, and 2000 may be divided naturally into two parts. First, we must forecast the baseline emission patterns for each of the three target years, i.e., the expected emissions inventories in the absence of electric vehicle usage on any significant scale. (Uncertainties in these baseline projections, due in large part to unpredictable shifts in governmental policy, may suggest establishment of multiple baseline scenarios for one target year to demonstrate the extent to which such variations can affect the results of the analysis.) Then we must assess how the introduction of electric vehicles alters the baseline pattern in each target year. Recalling from Sec. 2 the two analysis methods described, we see that two levels of detail will be required in our emissions forecasts, a gross prediction of daily emissions on a regional basis to support the rollback analysis, and a detailed distribution of pollutant source contributions over the region on an hourly time scale as needed by the GRC chemical-diffusion model.

As will be seen in the following sections, data are available which allow reasonably detailed emission forecasts for HC, CO, and NO_x, the primary pollutants modeled in the GRC code. However, the chemistry of SO_2 and particulates in the urban atmosphere is, as yet, poorly understood. SO_2 is diminished with time under the action of processes known to include photo-oxidation. Identification of these processes is one of the objectives of the current EPA Regional Air Pollution Study (RAPS) program being carried out in the St. Louis area. Particulates, on the other hand, are generated in photochemical processes involving both background chemical species and particles, and anthropogenic pollutants such as SO_2 and reactive hydrocarbons. Thus the particulate burden is not simply the sum of its natural and man-made components. It has been estimated that the Los Angeles aerosol is about one-third natural background, one-third anthropogenic primary pollutants, and one-third chemically formed particulates generated by the presence of the man-made primary species.[27] Unfortunately, urban aerosol chemistry is even less well understood than SO_2 chemistry. We are therefore limited to considering SO_2 and particulate impacts via the rollback method (wherein chemical activity is ignored), and hence, we will only require predictions of SO_2 and particulate emissions on an aggregated scale (e.g., tons per day emitted in the region).

5.2 VEHICULAR EMISSIONS

As configured for the Los Angeles region, the emissions module of the GRC code aggregates HC, CO, and NO_x emissions in 2-mile-by-2-mile squares. Vehicular emissions in each grid square are calculated as functions of average gram-per-mile emission factors for the vehicle mix, including light and heavy duty vehicles, daily surface street and freeway vehicle miles traveled (VMT), times of day (with separate time distributions for surface streets and freeways), and vehicle average speed, itself a function of location and time. In the absence of emission control strategies which alter the character of traffic peaking, such as staggering of working hours, we will not need to adjust the time distributions. In order to forecast mobile source emissions, we will need predictions of future traffic patterns which determine VMT and average speed distributions, and estimates of average vehicle emission factors for the years 1980, 1990, and 2000.

5.2.1 Vehicle Miles Traveled and Average Speed Distributions

We have at our disposal several methods for estimating future traffic patterns in the Los Angeles area. The simplest approach involves scaling our current VMT distributions (from Ref. 28, circa 1968) by the appropriate ratio of future to 1968 vehicle registrations in the area. This method has obvious drawbacks, primarily that it does not reflect future highway or mass transit construction, nor could it predict changes in vehicle speed distributions resulting from the increased VMT. Nevertheless, it is very easy to calculate and would provide a basis for judging the reasonableness of VMT results obtained by other methods. We are also obtaining from the cognizant county agencies overall predictions of expected vehicle populations. With some engineering judgment, these data may be used to update our 1968 VMT distributions incorporating knowledge of planned freeway additions. Finally, in connection with our work for the California Department of Transportation, we are obtaining from the Los Angeles Regional Transportation Study (LARTS) detailed projections of expected traffic in the Los Angeles area separated into freeway and surface streets VMT by grid square. The LARTS projections are being made for the planned freeway system as operational in the target years of 1985, 1990, and 2000. We anticipate that it will probably not be possible to use the LARTS data directly as their projections of population, per capita vehicle ownership, and driving habits appear to conflict with our estimates based on past history and current trends. However, since the LARTS traffic distributions are calculated from detailed network flow modeling of the planned street and freeway system, they will provide a good basis for scaling with predicted total VMT.

Thus our approach for predicting VMT and average speed distributions is to use the first two techniques mentioned above for the relatively near term target year of 1980 when shifts in traffic due to new highway or mass transit construction are not a significant factor, and to use distributions based on the LARTS projections, but tempered by total VMT data from the counties and our own population and transportation projections (see the companion papers, Refs. 29 and 30) for the years 1990 and 2000.

5.2.2 Average Vehicle Emission Factors

The average gram-per-mile pollutant emissions from the vehicle population in a given year are weighted combinations of emissions from light-*

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*For purposes of Federal and State emission control standards, vehicles weighing 6000 pounds or less are defined as "light duty"; those 6001 pounds and over in gross weight are classified as "heavy duty" vehicles.

and heavy-duty vehicles of various model years and ages, which are driven varying numbers of miles in their average use. Since 1966, the pollutant emissions from vehicles sold in California have been subject to State, and subsequently, Federal limitations by model year. Compliance with standards is determined by emissions collected from the vehicle during operation over a prescribed speed-time schedule referred to as a driving cycle. It is these driving cycle emission factors which serve as the common basis permitting meaningful combinations of emissions over a range of vehicle model years. Current standards are based on the Federal Driving Cycle[31] (FDC) which was designed to simulate average vehicle operation during peak traffic hours within 7 miles of the central business district. The resulting simulated trip covers 7.47 miles at an average speed of 19.6 mph. Empirical speed correction techniques will be applied to predict emissions at other speeds under both peak and off-peak traffic conditions.[32,33]

Given a calendar year for which average vehicle emission factors are required, the model year emission factors for all prior years are summed after being weighted by three factors; (1) a deterioration factor which accounts for losses in effectiveness of emission control systems with vehicle mileage, (2) the fraction of the daily VMT contributed by vehicles according to their ages and use, and (3) a speed correction factor for speeds other than the driving cycle average speed. In general, all of these factors will be functions of vehicle model year. Of course, in practice it is not necessary to consider all model years prior to the calendar year of interest, as after a certain age is reached the mileage contributions become negligible.

Reference 33, compiled by GRC under the sponsorship of the California Department of Transportation, details the above described calculations for various mixes of light and heavy duty vehicles sold in California, for target calendar years from 1967 to 2000, providing us with baseline vehicle emission factors of HC, CO, and NO_x for 1980, 1990, and 2000.

These baseline emissions are predicated on compliance with the current schedule of emission standards applicable to vehicles sold in California, and include the effects of the interim California standards for 1975 set by EPA on April 11, 1973[34] and the one year delay of the 1976 NO_x emission standard granted by EPA on July 30, 1973.[35] It is noted in Ref. 33 that after 1990 heavy duty vehicles will become the dominant contributors to vehicular emissions even if they satisfy presently contemplated emission standards, suggesting that it may be desirable to postulate as reasonable the application of some further tightening of heavy duty vehicle emission standards after 1975.* Otherwise, vehicular emissions in 1990 and 2000 will be practically insensitive to reductions in passenger car emissions.

In other calculations,[38] we have assessed the possible impact on NO_x emissions of California's program to retrofit NO_x controls on 1966 through 1970 model year cars, and determined that by 1980 the change in average emissions for the vehicle mix will already be negligible.

Expected trends in vehicle sales and use indicate that the vehicle age and use distribution will not change noticeably from that employed in Ref. 33, unless drastic public policy forces such as an emissions tax are instituted. Such a policy could result in lower average emissions in 1980 due to vehicle population shifts towards newer cars, but by 1990 the vehicle mix will consist entirely of vehicles with the final '76-'77 or later controls without any additional government coercion.

Although they are not often discussed, Ref. 1 shows that SO_2 emissions from vehicular sources in Los Angeles are 35 tons per day. This is comparable to SO_2 emissions from power plants (also 35 tons per day) and petroleum-related industries (55 tons per day). We will employ gram-per-mile SO_2 and particulate emission factors from Ref. 36 to calculate daily emissions of those pollutants for the planned rollback analysis.

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*Subsequent work did not assume that heavy duty vehicle emissions would be controlled more stringently than required by present laws.

The manner in which our characterization of the baseline vehicular emissions will be altered by the introduction of electric vehicles will depend on their role in the vehicle mix. Electric cars will, of course, emit no hydrocarbons, nitrogen oxides, or sulfur oxides. Hence, as far as these emissions are concerned, the use of electric cars having limited top speed capability can be simulated by general reductions of surface street VMT in proportion to the electrics' penetration of the small car market (taking into account the fraction of vehicle trips which have no freeway segment). Evaluating the air quality effect of an advanced electric capable of most or all of the urban trips now performed by conventional cars would involve recalculation of the average vehicle emission factors for the target calendar years after appropriate adjustment of the emission factors for previous model years in which electrics were sold. Emissions of particulates due to tire wear, brake linings, etc., will be assumed to be the same as for conventional autos. Particulate emissions in exhaust fumes will, of course, be eliminated in electric cars and appropriate adjustments will be made to account for this.

5.3 STATIONARY SOURCE EMISSIONS

The GRC photochemical-diffusion model employs separate specifications of stationary point source emissions from power plants and oil refineries, and aggregates emissions from distributed stationary sources (e.g., gasoline marketing, dry cleaning, solvent coating, etc.) by grid square. Each of the three stationary source types has its own diurnal time distribution which determines the fraction of total daily emissions occurring in each hour of the day. In this section we will outline the procedures to be employed in predicting daily emissions of HC, NO_x, SO_2, and particulates from these three source categories, and their spatial and temporal distributions. Stationary source emissions of CO may be safely neglected since they contribute about 0.1% of the total daily CO burden in the L.A. Basin.[1]

5.3.1 Power Plants

In a companion report,[37] we have developed baseline forecasts of electric power demand in the Los Angeles area which are compatible with our fundamental assumptions regarding population growth. Reference 37 supports three assumptions which are of importance to our estimation of future power plant emissions in Los Angeles and environs:

1. Except for those already under construction, no new power plants (nuclear or thermal) will be located in the SCAB. Any additional power generated in the region will be produced by uprating existing units, by retrofiting existing units with combined cycle* capability, and by construction of a few extra units at established thermal plants.
2. Natural gas is not expected to be available in any significant amount for power generation, as the available supply will probably be allocated to meet increasing residential demands. Hence, the thermal plants in the region are expected to be almost entirely oil fired after 1980. (Currently, increased residential demand for natural gas forces power plants and industry to use low sulfur fuel oil during the winter months. Residential demand from April to November is generally low enough to permit power plants and industry to use natural gas.)
3. While the availability of low sulfur oil ($\leq$0.5 percent by weight) may be a problem in the mid-1970s, the economics and technology of desulfurization indicate that low sulfur oil or a non-petroleum equivalent should be in ready supply by 1980 and for the remainder of the forecast period.

By the year 2000, nuclear stations sited outside the basin are expected to provide the major fraction of electrical generation capacity, meeting most of the continuous basic demand together with some hydroelectric sources. Early in the forecast period, fossil fueled plants (some coal fired plants outside the SCAB and the oil fired facilities within the region) will be providing some of the base load power and all of the peaking capacity. Figure 5.1 shows our baseline projection for the peak demand to be met by the generating facilities that really concern us here, the oil fired plants sited in the SCAB. As the availability of nuclear power increases, less and less of the oil fueled plant capacity will be used to satisfy the base load. Figure 5.2 plots the resulting daily power cycle in the peak demand month (August) for the years 1980, 1990, and 2000. These curves provide the baseline time distribution functions needed for our detailed forecasts of power plant emissions. Using data obtained from Southern California Edison (SCE), the Los Angeles Department of Water and Power (LADWP) and the cities of Glendale, Pasadena, and Burbank to predict individual site capacities, we will distribute the peak demand (Fig. 5.1) geographically in proportion to those capacities.

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*Combined cycle refers to systems employing a combination of the Brayton and Rankine cycles, i.e., a direct combustion turbine (like a jet engine turbine) is employed both to drive a generator directly and to produce hot exhaust gases which are used to boost the output of the basic steam turbine unit.

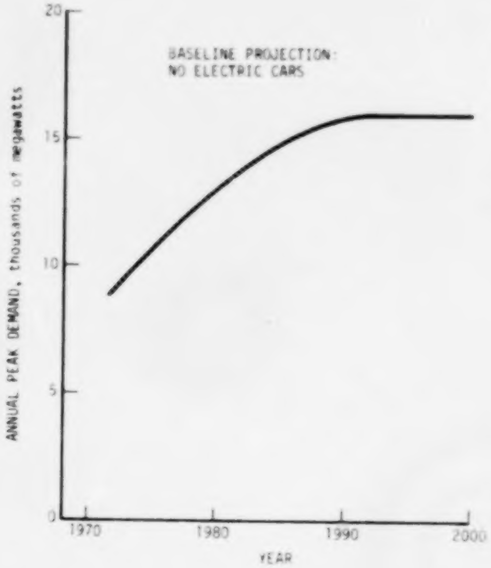

Figure 5.1. Baseline Projected Peak Demand for Electricity Generated by Oil Fired Plants in the South Coast Air Basin

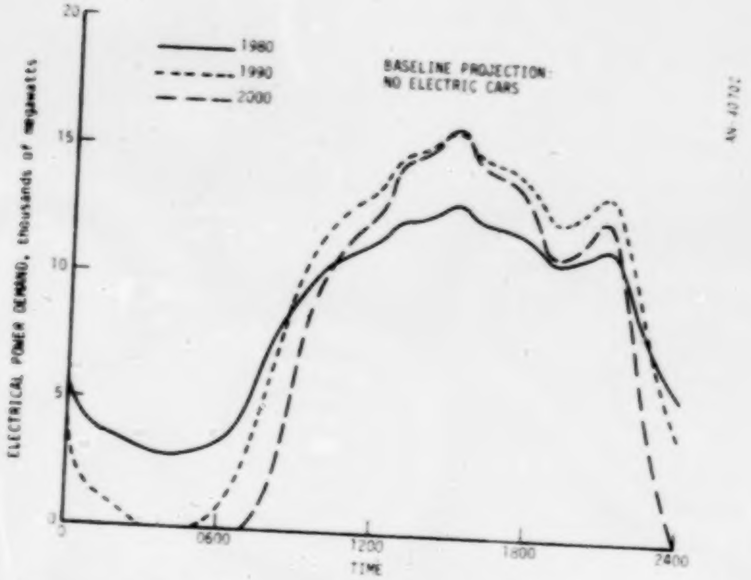

Figure 5.2. Projected Baseline Diurnal Power Demand on Oil Fired Power Plants in the Los Angeles Area for Peak Demand Month (August)

Reference 36 gives the emission factors shown in Table 5.1 for oil fueled power plants. Hydrocarbon emissions from power plants contribute less than 0.2 percent of the HC burden and hence are considered negligible.

Thus, all that remains is to translate megawatts of power generated into gallons of oil burned, and we have completed our baseline forecast

TABLE 5.1

OIL FIRED POWER PLANT EMISSION FACTORS,[36] POUNDS PER THOUSAND GALLONS

	NO_2	SO_2	Particulates
Steam Boiler	105	157(S)	8
Combustion Turbine	120	142(S)	8.4

(S = percent by weight of sulfur in the oil) of power plant emissions. Of SCE's current generating capacity in the Los Angeles region, only 10 percent comes from gas turbine generators, so that the overall operating efficiency of their systems is dominated by that of the older steam plants. On the average, about 36 percent of the fuel energy input is realized as electricity output. According to SCE forecasts, this efficiency is not expected to improve noticeably as new capacity comes on line. Therefore we plan to assume that all oil-fired units are of the steam type for purposes of emissions calculations. Using a 36 percent conversion efficiency and a fuel energy content of 145,000 Btu/gal we find that the average fuel consumption is 65.4 gal/MW-hr. It should be noted that these emission factors do not include the effects of any emission control efforts, e.g., off-stoichiometric or two-stage combustion, flue gas recirculation, low excess air, etc. Where calculation of the uncontrolled emissions yields a result which would exceed a Federal, State or local emission standard, the emissions will be assumed to just meet the standard, reflecting the application of some unspecified control technique.

When we have completed our baseline air quality calculations, we will need to modify the diurnal power demand curves of Fig. 5.2 to incorporate the added demand associated with recharging of electric car batteries. Most of the added demand will take the form of a continuous load starting at 10:00 or 11:00 pm and ending at 6:00 or 7:00 am. A small fraction of the total recharging load will be spread uniformly over the remainder of the day. The magnitude of the total load will depend on the number and types of the electric vehicles in each scenario, but a preliminary calculation[37] shows that sufficient off-peak generation capacity will exist to service over five million cars (out of a projected vehicle population of 6.7 million cars) in 1980 and more in the later years.

5.3.2 Oil Refineries

On a regional basis, emissions from oil refineries are relatively small, but since refineries are concentrated sources their emissions can be important on the local scale. The 1968 data base[28] used in the GRC code simply prorates total oil refinery emissions as reported by the Los Angeles County APCD to individual refinery locations according to their crude oil capacities. Current uncertainties as to future oil supplies in the US make it difficult to forecast oil refinery activities with confidence, but we will take the view that any real energy shortage which can be eased by the expansion of refining capacity will probably lead to relaxations of environmental restraints opposing that expansion. Therefore, reasoning that it is national demand which will be the prime consideration in determining gasoline and fuel oil production, we will scale oil refinery emissions in the SCAB with the projected national population to arrive at an emissions forecast for 1980, 1990 and 2000. Emissions to be treated in this fashion include reactive HC, NO_x, SO_2 and particulates.

5.3.3 Area Sources

Included in the distributed source category are activities ranging from industrial and commercial operations to residential living. Within the LAAPCD, emissions from these sources contribute from 9 to 42 percent of total emissions (except for CO) depending on the pollutant.[1] However, because they are spread over large areas, these emissions are relatively unimportant on the local level. We will use the regional population as a basis for scaling total area source emissions to 1980, 1990, and 2000 levels. For the detailed analysis, we intend to use general land-use plans from the various counties (Los Angeles, Orange, Riverside, and San Bernardino) as a guide for projecting the distribution of area source emissions. We will correlate our present emissions distribution with local zoning using three-to-five zone types (e.g., industrial, residential-commercial, residential), and then use these emissions/zoning relationships to construct future emission distributions from planning maps.

Only one category of distributed source emissions is directly affected by the infusion of electric cars into the vehicle mix, that being the petroleum marketing area. In 1970, hydrocarbon emissions from various vehicle and underground tank filling operations contributed about

13 percent of all HC emissions from stationary sources. This amounted to less than 4 percent of the total HC burden in 1970, but as baseline vehicular emissions reach their minimum levels, around 1990, the importance of these emissions will be roughly doubled. Therefore in scenarios where the electric car fraction of the vehicle mix is large enough to reduce gasoline sales significantly from their baseline levels (say 20 percent or more) we will have to adjust area source HC emissions accordingly.

6 AIR QUALITY IMPACT MATRIX

In previous sections we discussed the relationship between electric vehicles and air quality and outlined an approach designed to quantify this interdependence. The heart of the method consists of using an air quality simulation model to relate pollutant emissions and air quality. This section describes the actual cases considered in the simulation.

The cases considered are shown in Table 6.1.* In selecting the cases we have gone beyond a strict parametric analysis (Cases I-III) in an attempt to evaluate the effects of certain public policies on the air quality impact of electric cars. The various cases also serve to check the sensitivity of the results to the assumptions inherent in the analysis. It is inevitable that a study of this kind will always raise questions about a multitude of situations that are worthy of consideration. The

TABLE 6.1

MATRIX OF AIR QUALITY IMPACT CASES

(Numbers shown in table are the priorities assigned to the various cases.)

	Case	Year		
		1980	1990	2000
I	Baseline	1	1	1
II	Low Level of Electric Car Use	2	2	1
III	High Level of Electric Car Use	1	1	2
IV	High Level of Power Plant Emissions	3		
V	Effectiveness of EPA Transportation Controls	3		
VI	Low-Pollution Conventional Cars	4		
VII	Delayed Emission Controls for Conventional Cars	4	4	

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*Cases finally considered in the analysis were Cases I, III, and VII. The emissions range covered by these cases encompasses the remaining cases and it was deemed unnecessary to carry those out.

cases included in Table 6.1 are the result of our posing our own "What if...?" questions and then selecting what appear to be the most important cases. The scenarios have been matched to the time period when we have judged that the maximum impact would be felt. The numbers shown in Table 6.1 represent the priority assigned to each case.

Referring to Table 6.1, we note that the first three cases form the basis of the parametric analysis. Case I, the baseline case, assumes that no electric cars are in use. The forecasting methodology used to establish emissions levels for Case I has been described in Sec. 5. Cases II and III are perturbations of the baseline case in that the baseline emissions are altered by the introduction of certain low and high levels of electric vehicle use. The specific use levels will be determined in a separate task of the study.* Note that in 1980 and 1990 Case II gets a lower priority than Case III, and that this is reversed in 2000. The reason for this is that if the high level of electrics in 1980 and 1990 fails to yield significant gains in air quality, then it is probably unnecessary to consider Case II since the gains, if any, would be even smaller. In 2000 the situation is reversed in that the "low" level of electrics may be such as to improve air quality to within ambient standards and thus an even higher level of electrics would be known to meet standards by implication.

Case IV considers the possibility that future power plant emissions of SO_2 and NO_x may be higher than expected. This could come about if there are delays in the importation of natural gas, unexpected difficulties with coal gasification, or a possible lack of effectiveness of SO_2 and NO_x emission control technology. As indicated in Table 6.1, we would expect the major impact of such eventualities to occur in 1980.

Case V considers the effectiveness of the transportation controls for Los Angeles recently promulgated by EPA.[24] Without gasoline rationing, it is expected that the new controls would reduce VMT by a minimum of 14 percent and a maximum of 43 percent. We want to know what effect this would have on electric vehicle use and on air quality. For example, a plausible scenario is that these measures may exceed the threshold of inconvenience of people and that this would act to increase the use of electrics. Accordingly, we may see significant gains in air quality improvements when the EPA measures are combined with electric vehicles.

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* See also the footnote on p. 6-4.

Case VI has been included in an attempt to answer the question: What would be the air quality impact of electric vehicles if somehow the emissions of conventional cars can be made lower than is presently contemplated? If such an event materializes we would have electrics competing with low-emission vehicles and the air quality gains due to electrics could be diminished. For example, such a circumstance might come about if a stiff emissions tax were placed on all vehicles. This would encourage car owners either to eschew cars altogether or to buy newer, and presumably low-pollution, conventional cars, thereby reducing overall emission levels. Of course, such a policy might also have the effect of encouraging the purchase of electrics. We have judged the maximum impact of such an eventuality to occur in 1980, since by 1990 and 2000 technological changes together with a normal turnover of the auto population would indeed be placing electrics in competition with low-pollution conventional vehicles.

The last case, Case VII, is the converse of Case VI. It has been included in response to the current efforts to delay the implementation of vehicular emission controls. In fact, one-year extensions have already been granted both for CO and HC controls to 1976 and for NO_x controls to 1977.[22,23] The attractiveness of electric cars from an air quality standpoint would of course be enhanced under these circumstances.

7 ANALYSIS AND DATA DISPLAYS

In this section we describe the analysis of the air quality computations and introduce the devices we expect to use to display the results.

The Clean Air Act, as amended, required the promulgation of primary and secondary air quality standards. Primary standards are designed to protect human health whereas secondary standards are intended to protect welfare. At the present time standards exist for six major pollutants; these are shown in Table 7.1. These standards are subject to revision as new information becomes available; in fact, the NO_x standard is currently under critical scrutiny.[18] Such scrutiny notwithstanding, air quality is presently defined in terms of the standards.

Our basic problem is to determine air quality as a function of electric vehicle use for the three target years. Thus for each of the six pollutants of interest we will obtain a plot similar to that shown in Fig. 7.1.* Plotted on the graph will be the highest concentration of the pollutant computed at any point in the region of interest. The concentrations obtained using the rollback equation will be tabulated and compared with those produced by the GRC model. Since emissions form the basis for the application of rollback, mobile and stationary source emissions for the various cases will be displayed in tabular form. As is shown in Fig. 7.1, by superimposing the air quality standard on the graph we can determine the level of use which attains the standard.

It is useful to display the information on Fig. 7.1 in a different way as indicated in Fig. 7.2.* In Fig. 7.2 we plot the normalized concentration of each pollutant versus the level of electric car use for the year y , where the normalized concentration is defined as the pollutant concentration divided by its air quality standard. Thus the normalized

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*Later analysis showed that the perturbations on air quality induced by electric cars are relatively small. Accordingly, we departed from a strict parametric approach and considered only upper bounds on electric car use.

TABLE 7.1

NATIONAL AMBIENT AIR QUALITY STANDARDS[19]

Pollutant	Level Not to Exceed		
	Primary	Secondary	
SO_2	80 μg/m^3 (0.03 ppm)	60 μg/m^3 (0.02 ppm)	(a)
	365 μg/m^3 (0.14 ppm)	260 μg/m^3 (0.1 ppm)	(b)
Particulate Matter	75 μg/m^3 (c)	60 μg/m^3	(c)
	260 μg/m^3 (b)	150 μg/m^3	(b)
Carbon Monoxide	10 mg/m^3 (9 ppm)	Same	(d)
	40 mg/m^3 (35 ppm)		(e)
Photochemical Oxidants	160 μg/m^3 (0.08 ppm)	Same	(e)
Hydrocarbons	160 μg/m^3 (0.24 ppm)	Same	(f)
Nitrogen Oxides	100 μg/m^3 (0.05 ppm)	Same	(a)

(a) Annual arithmetic mean.

(b) Maximum 24-hr concentration not to be exceeded more than once a year.

(c) Annual geometric mean.

(d) Maximum eight-hour concentration not to be exceeded more than once a year.

(d) Maximum one-hour concentration not to be exceeded more than once a year.

(f) Maximum three-hour concentration (6-9 am) not to be exceeded more than once a year.

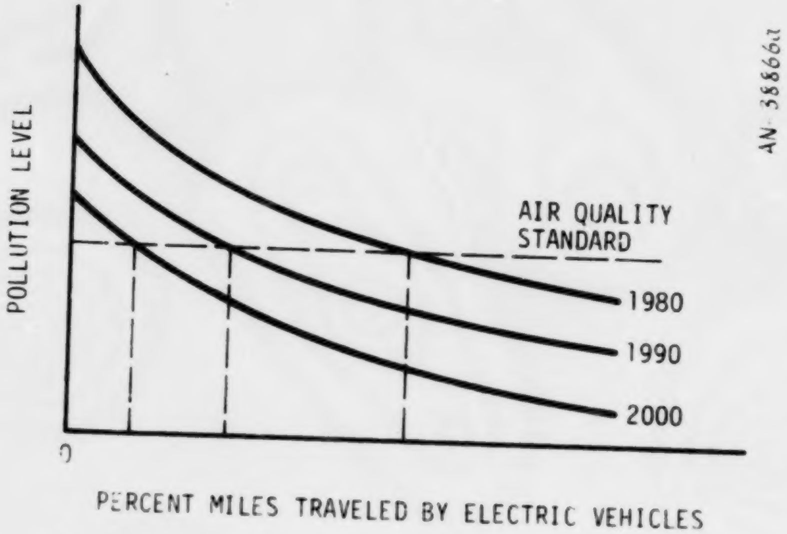

Figure 7.1. Typical Plot of One Species Concentration Versus Electric Car Fraction

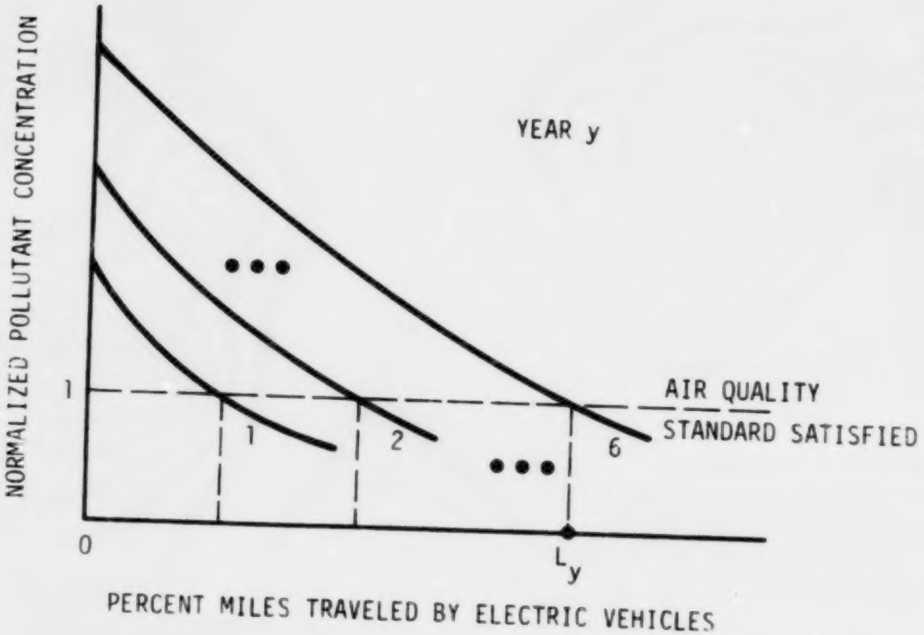

Figure 7.2. Plot of Normalized Pollutant Concentration Versus Electric Car use for a Particular Year. Each Curve Corresponds to one Pollutant

concentration is unity when the air quality standard is achieved. Figure 7.2 allows us to compare at a glance the varying degree of effectiveness which the use of electric cars has on the six pollutants. In addition, because the concentration is normalized, we can read directly from the ordinate the fractional change in air quality that occurs when the use of electrics increases. If we let ℓ_i , $i = 1, 2, \ldots, 6$, be the level of electric car use which meets the standard for the ith pollutant, then, clearly, $L_y = \max(\ell_1, {}_2, \ldots, \ell_6)$ is the use level which attains all the standards for the year y . The value of L_y is also placed in evidence in Fig. 7.2. The values of L_y obtained with the GRC model and with rollback will also be compared.

The second part of the air quality impact analysis consists of obtaining estimates of overall air quality for various levels of electric car use. A parameter which is useful in this respect is the fraction of the time which we can expect the air quality to satisfy the standards. Another useful indicator is the median pollutant concentration, i.e., the concentration which is exceeded half the time. The two indicators will be displayed in tabular form. However, we caution that the usefulness of these parameters will be determined by the size of their respective confidence intervals.

APPENDIX
DERIVATION OF AIR QUALITY STATISTICS

A.1 INTRODUCTION

As mentioned in the text, it is desired to obtain statistical information about the general quality of the air from the predicted worst-case pollutant concentrations. In particular, Sec. 6 of the text described two indicators which appear to be especially useful in this respect. The discussion that follows describes the methodology used to determine these indicators.

The first step in deriving air quality statistics is to define the functional form of the probability of occurrence of pollutant concentrations. Larsen[7,8] has shown that pollutant concentrations are generally distributed lognormally. We note, however, that we will process Los Angeles air quality data to test whether the lognormality hypothesis holds and shall use the proper distribution function to obtain the desired air quality predictions. For completeness, Sec. A.2 and A.3, respectively, describe properties of the lognormal distribution and the estimation of its parameters. Section A.4 then explains the method used to determine the desired statistics, including a discussion of the sources of error associated with the derived quantities.

A.2 THE LOGNORMAL DISTRIBUTION[20,21]

Let X be a random variable whose distribution is gaussian with mean μ_X and variance σ_X^2 and define a new random variable Y by

$$Y = \exp(X) \tag{A.1}$$

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Then Y is said to be lognormally distributed. The probability density function (pdf) of Y is readily obtained from the gaussian pdf and is given by

$$p(y) = \frac{1}{y\sigma_X \sqrt{2\pi}} \exp\left[-\frac{1}{2} (\log y - \mu_X)^2/\sigma_X^2\right] \quad ; \quad (y > 0) \qquad \text{(A.2)}$$

Thus, as defined here, the lognormal distribution is completely specified by two parameters.* Using the properties of the moment-generating function of the gaussian pdf we can ascertain that the mean and variance of Y are given by

$$\mu_Y = \exp\left(\mu_X + \frac{1}{2}\sigma_X^2\right) \qquad \text{(A.3)}$$

$$\begin{aligned}\sigma_Y^2 &= \exp(2\mu_X + \sigma_X^2)\left[\exp(\sigma_X^2) - 1\right] \\ &= \mu_Y^2\left[\exp(\sigma_X^2) - 1\right]\end{aligned} \qquad \text{(A.4)}$$

In our case, the pollutant concentration corresponds to Y and it is convenient to reverse the process by defining $X = \log Y$. The gaussian distribution is then defined in terms of the parameters of the lognormal function by solving Eqs. A.3 and A.4 for μ_X and σ_X^2 as functions of μ_Y and σ_Y^2 , viz.,

$$\mu_X = \log \mu_Y - \frac{1}{2}\log(1 + \sigma_Y^2/\mu_Y^2) \qquad \text{(A.5)}$$

$$\sigma_X^2 = \log(1 + \sigma_Y^2/\mu_Y^2) \qquad \text{(A.6)}$$

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*It is also possible to generalize the definition of the lognormal pdf to include three parameters, but this is not pertinent for our purposes. See Refs. 20 and 21 for a more detailed explanation.

although these equations may not necessarily be the best estimators of the mean and variance.

Let us now define a unit normal variable U by the linear transformation

$$U = (X - \mu_X)/\sigma_X \tag{A.7}$$

The pdf of U is gaussian with zero mean and unit variance. Making use of Eq. A.1 we can express Y as a function of U as shown below

$$\log Y = \mu_X + \sigma_X U \tag{A.8}$$

Clearly, Eq. A.8 defines a straight line with intercept μ_X and slope σ_X . Since a probability is associated with each value of U , then for graphical purposes Eq. A.8 also defines the cumulative distribution function of log Y . Note that when $U = 0$ then $P[U \leq 0] = 0.5$. Hence the median value, i.e., the 50th percentile, of Y is given by

$$\text{median } Y = \exp(\mu_X) \tag{A.9}$$

Thus the "intercept" of the line is actually located at the 50th percentile.

Consider a sample of n values of Y , and let those values be defined by y_i, $i = 1, \ldots , n$. Then the sample geometric mean is defined by

$$m_g = \left(\prod_1^n y_i\right)^{1/n} \tag{A.10}$$

However, we have that

$$\log\left(\prod_{i}^{n} y_i\right)^{1/n} = \frac{1}{n}\sum_{1}^{n} \log y_i = \frac{1}{n}\sum x_i = m_X \qquad \text{(A.11)}$$

where m_X is the sample mean of the gaussian variable. Hence, from Eqs. A.10 and A.11

$$m_g = \exp(m_X) \qquad \text{(A.12)}$$

If the actual mean of the gaussian distribution is equal to the sample mean then $\mu_X = m_X$ and we can formally define the geometric mean of the lognormal distribution by

$$\mu_g = \exp(\mu_X) \qquad \text{(A.13)}$$

Comparing Eqs. A.9 and A.13 it can be seen that the median of Y is equal to the geometric mean of the distribution. Moreover, from Eqs. A.3 and A.13 we can see that

$$\mu_Y > \mu_g \qquad \text{(A.14)}$$

hence the percentile associated with the mean of Y is greater than that associated with its geometric mean, the difference in percentile being a function of σ_X.

We have now defined some of the relevant properties of the lognormal distribution and its relationship with the gaussian function. It remains to use these results in a setting related to air quality. This brings us to the task of estimating the parameters which specify the distribution using the worst-case predictions from our simulations.

A.3 ESTIMATION OF PARAMETERS

A.3.1 General

Two parameters suffice to specify the density function of pollutant concentrations: μ_X and σ_X. Eq. A.8 tells us that this amounts to specifying the intercept and the slope of a straight line. We note, however, that the air quality simulations do not attempt to predict these two quantities. Instead, the simulations predict worst-case pollutant concentrations. Since any point on the line qualifies as the intercept, we need not worry about estimating μ_X. We can thus use the predicted worst-case concentration as the intercept provided we assign a probability of occurrence to it.

Estimating the slope is another matter. The simulations will not help us to obtain statistically significant estimates of the slope because, for economic reasons, the size of the sample available for estimation is too small. An independent means of estimating the slope is thus necessary and we shall use experimental data obtained by the Los Angeles Air Pollution Control District for this purpose.

A.3.2 Use of Worst-Case Predictions

The worst-case predictions of the air quality model provide a pollutant level to be located on the line defined by Eq. A.8. The question is: what probability of occurrence shall we assign to the predicted worst-case concentration?

One way to resolve this question is to analyze aerometric data to determine two pieces of information:

1. Given a predicted concentration, what is the historical frequency of occurrence of that concentration?
2. Do the data show a time trend for this frequency of occurrence?

This information places the prediction in the context of historical air pollution patterns and, by extrapolating the time trend, we can in turn put the prediction in a future setting. The uncertainties associated with the latter course are well recognized, however, and error bounds will be obtained for the projected probability.

An alternative, simpler method is to assign an a priori probability. To illustrate, the assigned probability could be based on considerations such as the fact that the meteorological conditions being used, i.e., a day in which a pollution episode occurs, have had a frequency of occurrence of 213/5840 (cf. p. 21). Other similar criteria may also be used to establish the desired probability. Which of the two alternative methods is best will be determined in the course of the analysis.

A.3.3 Estimating the Slope

Estimating the slope of the line is synonymous with determining the variance, σ_X^2 . The estimate will be obtained independently from the model's predictions using the aerometric data of Los Angeles. The estimation of σ_X^2 is a standard problem in statistics and many methods exist for this purpose (cf. Ref. 21, Ch. 5). The maximum likelihood estimator

$$s^2 = \frac{1}{n}\sum(x_i - \bar{x})^2$$

is especially convenient since it allows us to obtain exact confidence intervals for σ_X^2 . The confidence interval is given by

$$\left(\frac{(n - 1)s^2}{\chi_2^2} , \frac{(n - 1)s^2}{\chi_1^2}\right)$$

where χ_1^2 and χ_2^2 are suitable percentage points for the chi-square distribution with (n - 1) degrees of freedom. For example, for a 90%

confidence interval we would have $P(\alpha < \chi_1^2) = 0.05$ and $P(\alpha < \chi_2^2) = 0.95$, where $\alpha = (n - 1)s^2/\sigma_X^2$. Aitchison and Brown[21] have shown that the maximum likelihood estimator is also very reliable with respect to other estimators.

It is also necessary to determine any time trend which σ_X^2 may follow and we will test the data for the presence of any such trend.

A.4 DERIVATION OF AIR QUALITY INDICATORS

A.4.1 Method

The two indicators sought are:

1. The fraction of the time that air quality standards are exceeded
2. The median pollutant concentration

These two quantities are to be obtained for each pollutant for the several scenarios considered in the study. Their determination is a simple matter once the probability density function has been specified. By using log/probability paper we can plot a straight line in accordance with Eq. A.8 and the desired quantities can then be read off the graph. The graphical approach is also advantageous for displaying the error bounds.

A.4.2 Causes of Error

The accuracy of the indicators is determined by a combination of the following factors:

1. Accuracy of the model's predictions.
2. Errors in estimating the frequency of occurrence of worst-case concentration.
3. Errors in estimating the standard deviation of the distribution function.
4. Uncertainties in extrapolating time trends.

One of our main concerns is the way the various errors combine to affect the final result. Another item of interest is the sensitivity of the result to the various errors. Since the combination of errors can become complex, our preference is to report the results in the form of intervals to which, hopefully, a statistical confidence level can be assigned. By introducing perturbations in the various quantities involved we can obtain measures of sensitivity as well as assist in determining the size of the interval. If warranted, it may be useful to determine sensitivity coefficients for each of the quantities involved.

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**Task Report 3.

†Task Report 5.

TASK REPORT 7

AIR QUALITY IMPACTS OF ELECTRIC CARS
IN LOS ANGELES

J.R. Martinez
R.A. Nordsieck

ABSTRACT

Using electric vehicles has been proposed as a means of alleviating air pollution from automotive sources. This work investigates the changes in air quality which would occur in Los Angeles if various fractions of the conventional car population were replaced by electrics during the period 1980-2000. Primary pollutant emissions of both reactive and inert species are estimated for the study area, in the absence of electric cars, and under maximum electric vehicle mileage fractions of 20, 80, and 100 percent in 1980, 1990, and 2000. Emissions tradeoffs from vehicular to power plant sources are explicitly considered. Because of emissions shifts to power plants and the increased leverage of stationary sources in later years, only carbon monoxide shows the full benefit of electric car use. Hydrocarbon emissions are reduced 7 to 19 percent, particulates 4 to 21 percent, nitric oxide 1 to 12 percent, while sulfur dioxide increases 7 to 14 percent.

Air quality levels during the study period with and without the use of electrics are assessed by two methods: (1) assuming direct proportionality with emissions (linear rollback), and (2) simulation in the photochemical smog model (DIFKIN) developed at General Research Corporation, which includes chemical reactions and atmospheric transport effects. DIFKIN predicts maximum reductions of about 20 percent in ozone and nitrogen dioxide levels at the higher electric car fractions. Federal air quality standards for carbon monoxide and nitrogen dioxide are met during the study years under presently contemplated emission control schedules without electric cars, but ozone and sulfur dioxide standards are not. Ozone levels continue to exceed the Federal standards in spite of reductions approaching 20 percent due to electric cars. Increased power plant activity with the electric car recharging demand tends to increase sulfur dioxide levels, already above the statutory limits.

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1 INTRODUCTION

This report describes the results of a study to determine the impact on air quality caused by using various amounts of electric cars rather than conventional cars entirely in future years in the Los Angeles basin. An extensive description of the approach followed to determine the air quality impact of electric cars is found in Task Report 6.[1]

The study focuses on the years 1980, 1990, and 2000. For each of these years, projections of automotive and stationary emissions of air pollutants were determined under the assumption that no electric cars would be in use. These emissions were then adjusted according to the number of electric vehicles on the road which was determined from other studies.

The projected emissions were related to air quality using two different methods. One method uses the linear rollback formula, where air quality is presumed to vary linearly with emissions. The features and shortcomings of this approach are discussed in Refs. 1-3. The second method employs an air quality simulation model (DIFKIN) developed at General Research Corporation (GRC) under the sponsorship of the Environmental Protection Agency (EPA).[4,5] In essence, DIFKIN mathematically simulates atmospheric diffusion and chemistry to compute the concentrations of air pollutants such as ozone and nitrogen oxides using primary pollutant emissions of nitric oxide and reactive hydrocarbons as inputs.

The projected pollutant emissions for the years considered are discussed in Sec. 2. The air quality impacts of electric vehicles are described in Sec. 3, and Sec. 4 discusses the implications of the study.

2 FORECASTS OF POLLUTANT EMISSIONS

2.1 GENERAL

Baseline forecasts of pollutant emissions were made for 1980, 1990, and 2000. These baseline projections assume that no electric cars would be in use in any of the three target years. Basically, the projections consist of estimates of emissions of reactive hydrocarbons (HC), nitric oxide (NO), carbon monoxide (CO), sulfur dioxide (SO_2), and particulate matter. Each of these is associated with various land use and transportation patterns in the impacted area. Accordingly, the forecasts are based on regional transportation and land use plans prepared by governmental agencies in southern California. These various plans have been collected and summarized in Task Reports 2 and 3.[6,7]

The emissions estimates take two forms. One form consists of an aggregated areawide source inventory. In this case, all pollutant emissions of the same type, e.g., CO, are added together regardless of their geographical distribution. The second form preserves the geographical distribution of the sources. To do this, the study area (shown in Fig. 2.1) has been partitioned into a grid of 2-mile-by-2-mile squares, and all the sources within each square have been averaged over the area of the square. For each square, we have stationary and mobile source emissions, the latter being dependent on the number of vehicle miles traveled (VMT) in the road segments within the square and the former on the land use mix, e.g., industrial, residential, park, etc. Traffic information was obtained from the California Department of Transportation (CALTRANS), District 7, and the Los Angeles Regional Transportation Study (LARTS). Land use distribution was based on projections by the Southern California Association of Governments (SCAG). Appendix A describes in detail the data sources and methods used to estimate and extrapolate the inventory of pollutant emissions for the study area.

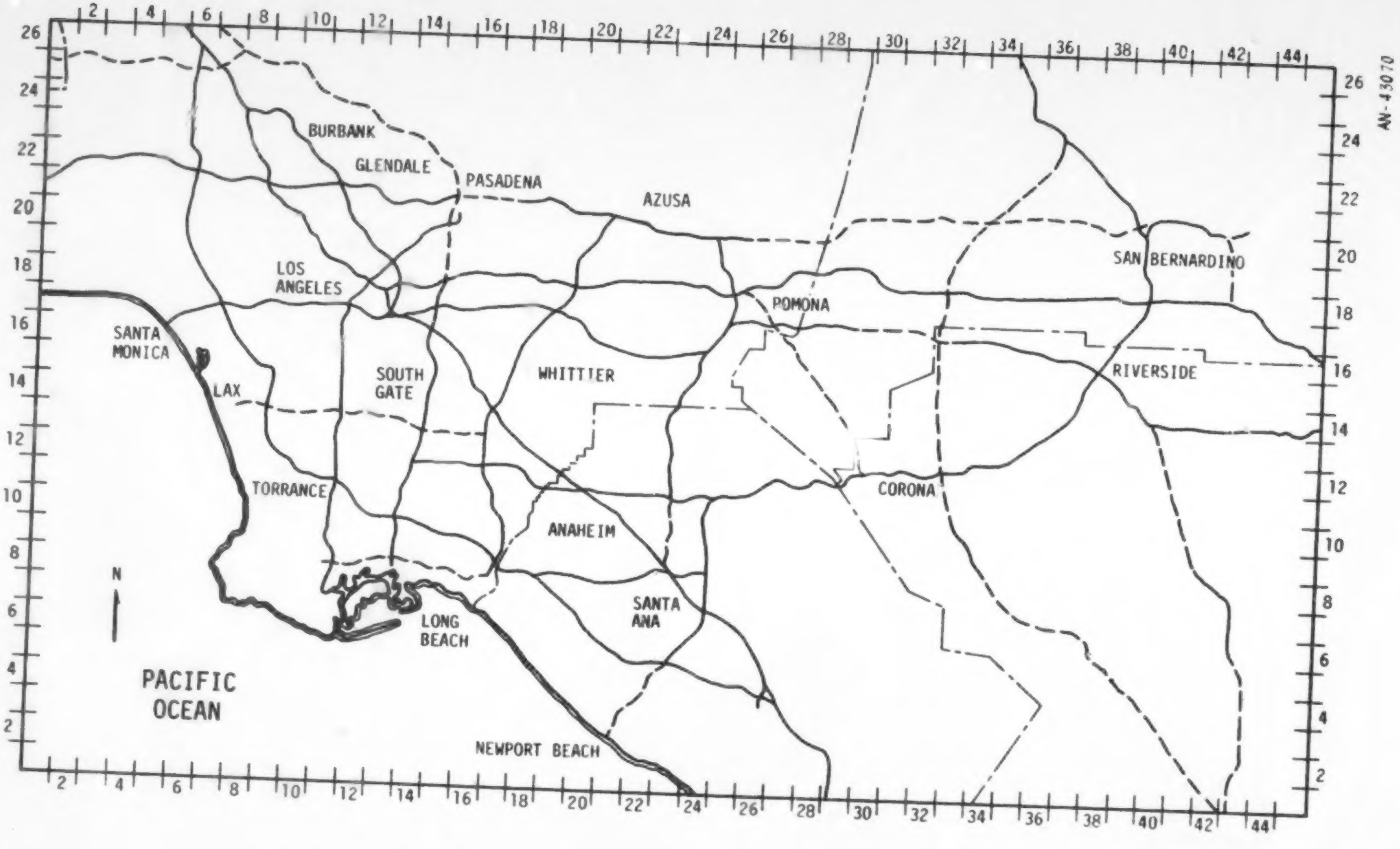

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Figure 2.1. Emissions Model Study Area

2.2 IMPACT OF PUBLIC POLICIES

To determine baseline emission levels, it is necessary to assess the direction of public policies which affect future emissions by instituting various abatement strategies. Two sets of such policies, both related to the Clean Air Amendments of 1970 and subsequent further amendments, provide the main thrust for emission control efforts. The first policy is the federal legislation which sets maximum levels of emissions from automobiles.[8] The second is the federal legislation which requires each state to submit a plan designed to control emissions.[9] These controls are needed in order to meet the national ambient air quality standards within each air quality control region (AQCR) in the nation. The Los Angeles area is one of these AQCRs. The plan submitted by a state is known as the state implementation plan (SIP) and is aimed at controlling stationary and mobile source emissions. Where vehicle emission controls alone are not expected to achieve the goals on schedule, land use and transportation controls are mandated. Examples of the latter include vehicle inspection programs, parking restrictions, and mass transit programs. Stationary emissions are controlled, for example, by regulating types of fuel that can be burned and by reducing evaporative losses at gas stations, to name but two proposed schemes. The law also imposes emission performance standards on all new stationary sources based on available technology.

Two scenarios emerge from these general public policy guidelines. The main scenario used in our baseline emission forecasts for all three target years is that auto emission controls are implemented as mandated by the law as amended up until August 1973, when interim standards for nitrogen oxides (NO_x) emissions were promulgated by the Environmental Protection Agency.[8] Further delays have since been proposed in the implementation of auto emission controls; hence, this scenario can be considered optimistic.

The second scenario considers the effect of the proposals that would delay for several more years the installation of auto emission controls and thus is the more pessimistic scenario.[10] These subsequent amendments would retain 1975 interim auto emission standards for HC and CO through the 1977 model year. In addition, we have adopted the more pessimistic interpretation of the proposed amendments regarding NO_x emissions: NO_x emission standards would remain at the 1974 level of 2 grams per mile forever. The second scenario has been targeted only for 1980 because the main impact of the delays will be felt that year and we shall designate it as case 1980d.

Regarding the SIP, under both scenarios we have assumed that the abatement strategies proposed by California for stationary sources will be as effective as forecast in the working documents developed by the state. A detailed breakdown of the assumed reductions may be found in Appendix A, Sec. A.6.

2.3 VEHICULAR EMISSION FACTORS

Table 2.1 shows the passenger car exhaust emission standards assumed to prevail in California for the period 1972-1977. Our baseline forecasts of automotive emissions use measured emissions data through the 1971 model year and the standards in Table 2.1 from 1972 on. No further changes are

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TABLE 2.1

CALIFORNIA EXHAUST EMISSION STANDARDS FOR PASSENGER CARS, grams per mile

	HC	CO	NO_x
1972	3.2	39	3.0
1973	3.2	39	3.0
1974	3.2	39	2.0
1975	0.9	9.0	2.0
1976	0.41	3.4	2.0
1977	0.41	3.4	0.40

shown after 1977 because the law currently does not require additional controls after that year. Already included in the table is the effect of one-year delays in implementing the final HC and CO controls (delayed from 1975 to 1976) and the final NO_x controls (delayed from 1976 to 1977), the delays having been promulgated in April and July 1973 for the former and in August 1973 for the latter.

Under the amendments to the Clean Air Act proposed in March of 1974 (see Ref. 10), the HC and CO standards shown in Table 2.1 would remain at the 1975 level through 1977. The values shown for 1977 would then come into effect in 1978. For NO_x , the more pessimistic interpretation of the proposed amendments is that the NO_x standard will remain at 2.0 grams per mile forever.

Finally, we note that the actual total vehicular emissions in a given year depend on the vehicle age distribution, the distribution of vehicular speeds, the amount of heavy-duty vehicles in the population, as well as on the emissions from vehicles in each model year. Thus computing vehicular emissions is a rather involved task. The effective vehicular emission factors for California for various years have been computed in Ref. 11. In computing these emission factors we have included the effect of deteriorating emission controls as a function of vehicle age. Information about the deterioration factors used for the various model years is also contained in Ref. 11. The emission factors used in our two scenarios have been determined following the methods established by Nordsieck[11] and assume that heavy-duty vehicles contribute 5 percent of the VMT (see Appendix A, Sec. A.3). A private communication from the California Department of Transportation (CALTRANS) indicates that the fraction of VMT contributed by heavy-duty vehicles in Los Angeles ranges between 5 and 10 percent. The lower figure was used in order to be consistent with other work performed by CALTRANS. Using a 10-percent contribution of VMT from heavy-duty vehicles would increase baseline total vehicular emissions in 1980 by 18 percent for HC, 14 percent for NO_x , and 27 percent for CO.

The percentage of vehicular and total emissions contributed by the 5-percent heavy-duty vehicle component is discussed in Sec. 2.6. Reference 11 contains tables of vehicular emission factors with various fractions of heavy duty vehicles in the populations, ranging from zero to 100 percent.

2.4 STATIONARY EMISSIONS

Stationary emissions are composed of HC, NO_x, particulates, and SO_2. Stationary sources of CO can be neglected since they contribute only about 0.1 percent of the total daily CO burden in the area.[12] Our main concerns are the respective contributions of power plants, oil refineries, and sources such as residential and industrial areas. The SIP impacts most heavily on HC emissions from area sources, the expectation being a 66-percent reduction in HC emissions from area sources from 1969 to 1980. Because of lack of data after 1980, we have assumed that no further changes in total HC emissions will take place. Power plants are discussed below; baseline estimates of total emissions for all sources are given in Sec. 2.6; and details of the emissions distributions are found in Appendix A.

2.4.1 Power Plants

Power plant emissions consist of NO_x, SO_2, and particulates; HC emissions are negligible and the NO_x is essentially NO. Of primary interest in this area are the expected changes in electric power demand which is supplied by fossil-fueled units. Projections of the fractions of electrical power demand supplied by several kinds of units, e.g., nuclear, fossil-fueled, hydro, are found in Task Report 5.[13] Table 2.2 shows the projected changes of in-basin fossil-fueled electric power generation without electric cars. From Table 2.2 it can be seen that this type of power generation increases slightly from 1980 to 1990 and decreases thereafter. The decrease is due to the increasing reliance on power from remote sources as well as on nuclear-powered units. Since power plant emissions are directly proportional to the generated power, they will follow the general trend indicated in Table 2.2. The estimation of these emissions is discussed in Appendix A.

TABLE 2.2

BASELINE PROJECTED AVERAGE ELECTRICAL POWER GENERATION BY FOSSIL-FUELED UNITS WITHIN THE STUDY AREA

(megawatts)

1980	1990	2000
8,450	8,700	7,350

2.5 PROJECTIONS OF VEHICLE MILES TRAVELED

The vehicular emissions are a direct function of the miles traveled by each vehicle. Table 2.3 shows the daily total of VMT in the study area for the three years of interest. The increases in VMT are of course related to expected increases in population as well as to changes in driving patterns.[7] The traffic data base and interpolation methods used to synthesize these VMT data are described in Appendix A.

2.6 BASELINE POLLUTANT EMISSIONS

Tables 2.4-2.6 contain the estimated values in tons/day of the pollutant emissions from the various sources for 1980, 1990 and 2000. In addition, Table 2.7 shows for 1980 the estimated changes in vehicular emissions caused by the newly suggested delays in the enforcement of auto emission controls which were proposed in March 1974 and which were discussed in Secs. 2.2 and 2.3. We emphasize that the hydrocarbon emissions consist of reactive hydrocarbons. Under our definition of reactivity, only benzene, acetylene, and C_1-C_3 paraffins are considered to be

TABLE 2.3

PROJECTED DAILY VEHICLE MILES TRAVELED IN THE STUDY AREA

(Thousands of Miles)

	1980	1990	2000
Freeways	64,933	73,408	82,251
Surface Streets	84,109	88,625	93,311
Total	149,042	162,033	175,526

TABLE 2.4
1980 BASELINE POLLUTANT EMISSIONS FOR LOS ANGELES AND ENVIRONS

(Tons/Day)

	NO	HC	CO	SO_2	Particulates
Vehicular	181.5	160.3	2202.8	22.4	91.2
Stationary Area Sources	106.0	160.7	--	195.3	96.9
Power Plants	113.3	--	--	362.0	12.6
Oil Refineries	48.8	33.7	--	60.6	11.0
Total	449.6	354.7	2202.8	640.3	211.7

TABLE 2.5
1990 BASELINE POLLUTANT EMISSIONS FOR LOS ANGELES AND ENVIRONS

(Tons/Day)

	NO	HC	CO	SO_2	Particulates
Vehicular	75.5	72.3	1084.2	24.4	99.2
Stationary Area Sources	140.8	160.7	--	213.1	105.7
Power Plants	116.2	--	--	372.0	12.9
Oil Refineries	53.7	37.1	--	66.7	12.2
Total	386.2	270.1	1084.2	676.2	230.0

nonreactive. This is more stringent than the criteria used by the Los Angeles Air Pollution Control District, which define benzene, acetylene, C_1-C_4 paraffins, and several other members of the paraffin and cycloparaffin family as nonreactive. The stricter definition of reactivity used in this report has been documented in Ref. 14.

The vehicular emissions of NO, HC, and CO shown on the tables reflect the distribution of mileage traveled by vehicles of various ages.

TABLE 2.6
2000 BASELINE POLLUTANT EMISSIONS FOR LOS ANGELES AND ENVIRONS

(Tons/Day)

	NO	HC	CO	SO_2	Particulates
Vehicular	80.6	77.1	1152.1	26.4	107.5
Stationary Area Sources	181.1	160.7	--	227.7	112.9
Power Plants	98.1	--	--	315.0	10.9
Oil Refineries	57.6	39.8	--	71.5	13.0
Total	417.4	277.6	1152.1	640.6	244.3

TABLE 2.7
1980 BASELINE VEHICULAR EMISSIONS FOR LOS ANGELES AND ENVIRONS WITH AND WITHOUT DELAYS IN IMPLEMENTING AUTO EMISSION CONTROLS

(Tons/Day)

	NO	HC	CO
With Delay	300.6	168.5	2328.2
Without Delay	181.5	160.3	2202.8

These figures also include the effect of the various speeds which normally prevail throughout the region as well as a 5-percent component of heavy duty vehicles such as buses and trucks. It is noted that these emissions decrease from 1980 to 1990 in spite of the increase in VMT. This is due to the constant addition of new cars with stringent emission controls. The situation is reversed from 1990 to 2000 because during this decade the increase in VMT outstrips the controls. Nevertheless, the vehicular emissions by 2000 are still relatively small compared to 1970.

The SO_2 and particulate emissions for vehicles were computed by applying emission factors of 0.13 g/mi for SO_2 and 0.54 g/mi for particulates (including particulates from the exhaust and tire wear) for light duty vehicles and 0.26 g/mi and 0.85 g/mi for SO_2 and particulates, respectively, for heavy duty vehicles which were obtained from Ref. 15. These emissions increase throughout the study period in proportion to VMT because so far no legislation is contemplated to control them.

Tables 2.4-2.6 reflect the fact that hydrocarbon emissions from stationary area sources are expected to remain constant through the study period. On the other hand, the NO from the same sources is expected to increase by 70 percent from 1980 to 2000.

The power plant emissions increase from 1980 to 1990 and decline thereafter in accordance with the planned power generating schedule shown on Table 2.2. The stringent NO_x, SO_2, and particulate emission controls used in Los Angeles have been taken into account in estimating the future emissions from power plants. Finally, emissions from oil refineries are expected to increase due to a projected expansion of refining capacity in 1980-2000.

Details of the techniques and assumptions employed in projecting future power plant and oil refinery emissions may be found in Appendix A. Referring to Table 2.7, it can be seen that the proposed delays in implementing HC and CO controls cause only very slight increases in total emissions in 1980: 5 percent for HC and 5.7 percent for CO. We recall that these delays are only through 1977, hence by 1980 we will have had two years of the stricter controls. By contrast, the NO emissions with the delay have been increased substantially, about 66 percent. This is due to the fact that the NO_x emission standard has been assumed frozen at 2.0 g/mi rather than decreasing to 0.4 g/mi as originally shceduled.

Table 2.8 shows the fraction of the total emissions of NO and HC which is due to vehicular sources. Note that the vehicular contribution to NO emissions decreases throughout the period. For HC, the contribution from vehicles decreases from 1980 to 1990 and increases slightly by

TABLE 2.8

RATIO OF VEHICULAR EMISSIONS TO TOTAL EMISSIONS
FOR 1980-2000 WITHOUT ELECTRIC CARS

	1980	1990	2000
NO	0.40	0.20	0.19
HC	0.45	0.27	0.28

2000. It is also noteworthy that the vehicular contributions are relatively small by 1990 and 2000. Thus, on an aggregated areawide basis, stationary emissions of NO and HC loom large in the future total emissions picture of the Los Angeles area. This is significant because the electric cars will be operating on a rather small portion of the total emissions and their leverage on air quality will be attenuated accordingly. It should be mentioned that the stricter definition of hydrocarbon reactivity causes the stationary hydrocarbons to assume a greater importance relative to mobile source emissions than they have been assigned in the past. For example, the fraction of total reactive hydrocarbon emissions attributed to vehicles in 1970 is 85 percent under the less strict definition of reactivity and 65 percent under the stricter reactivity criteria. Using the less strict reactivity definition the ratios shown in Table 2.8 for HC would change to 0.73, 0.55, and 0.56 for 1980, 1990, and 2000, respectively. Thus on an aggregated basis the leverage exerted on HC by electric cars is affected by the definition of reactivity. However, in many locations in the basin the emissions are dominated by vehicular sources and in those cases the impact of introducing electric cars can be significant.

Finally, some remarks are in order about the differential effects on emissions and air quality due to heavy duty vehicles. Table 2.9 shows the fractional contribution of heavy duty vehicles to vehicular and total baseline pollutant emissions under the assumption that heavy duty vehicles account for 5 percent of total VMT.

TABLE 2.9

FRACTIONAL CONTRIBUTION OF HEAVY DUTY VEHICLES TO VEHICULAR AND TOTAL BASELINE EMISSIONS FOR LOS ANGELES AND ENVIRONS

	NO		HC		CO		SO_2		Particulates	
	Vehicular	Total	Veh	Tot	Veh	Tot	Veh	Tot	Veh	Tot
1980	0.18	0.07	0.23	0.10	0.31	0.31	0.09	0.003	0.08	0.03
1990	0.31	0.06	0.33	0.09	0.67	0.67	0.09	0.003	0.08	0.03
2000	0.31	0.06	0.33	0.09	0.67	0.67	0.09	0.004	0.08	0.03
1980d	0.11	0.06	0.22	0.10	0.29	0.29	0.09	0.003	0.08	0.03

It should be mentioned in connection with Table 2.9 that present laws do not envision placing stricter controls on heavy duty vehicles as is being done to automobiles. The relatively uncontrolled trucks and buses thus contribute a large share of future vehicular emissions.

From Table 2.9 it is apparent that trucks and buses have a major impact on CO emissions in 1980 and beyond. This is the case even though in our calculations heavy duty vehicles account for only 5 percent of the VMT. Such a large component of CO emissions from heavy duty vehicles will naturally reduce the impact that electric cars can have since they are unlikely to supplant heavy duty vehicles.

The effect of heavy duty vehicles on NO and HC emissions is moderate, but tends to further erode any gains that may be attributed to electric cars. Heavy duty vehicles affect only slightly the vehicular and total emissions of SO_2 and particulates.

3 AIR QUALITY IMPACT OF ELECTRIC CARS

3.1 GENERAL

Our approach for determining air quality levels of photochemical pollutants consists of selecting various sites in the South Coast Air Basin which are presently afflicted with heavy air pollution. The sites selected are shown in Fig. 2.1. Meteorological conditions for a day (Sept. 29, 1969) in which an air pollution episode occurred were used to compute worst case pollutant concentrations at the selected locations using the DIFKIN air quality model. The pollutant levels were calculated by following the path of air masses which traverse the air basin and arrive at the selected sites at various times of the day. The air trajectories used in the computation are found in Appendix B. We also obtained estimates of pollutant levels by means of the linear rollback method. (See Ref. 1 for additional explanations regarding our methodology.)

The first step in the analysis is to calculate baseline air quality levels which may prevail in 1980, 1990, and 2000 without electric cars. Introducing electric vehicles perturbs emissions by reducing vehicular contributions and increasing the emissions from power plants; new air quality levels are then computed and compared with the baseline levels. The following sections discuss the components of the analysis.

3.2 CHANGES IN EMISSIONS DUE TO ELECTRIC CARS

The changes in total emissions caused by electric cars have been computed on the basis of upper bounds on electric car use. Table 3.1 shows these upper bounds for the various years. The criteria used to determine these upper limits are diverse and are found in Ref. 16. The use level of electric cars can be varied parametrically up to the upper bound of Table 3.1 and the emissions for these various use levels can be approximated by interpolating linearly between the baseline and upper bound emissions.

TABLE 3.1

UPPER BOUNDS OF ELECTRIC CAR USE

	1980	1990	2000
Cars, Millions	1.2	5.4	7.6
Daily Mileage, Millions	28	123	167
Percent of Total Daily Mileage	19	76	95
Percent Electric Cars	20	80	100

In introducing electric cars into the vehicle population, we have assumed that electrics replace conventional cars on a one-for-one basis with regard to VMT. Thus, for example, if electrics replace 20 percent of the cars in the population, the VMT due to conventional cars is reduced by 20 percent also. Since vehicular emissions are directly proportion to VMT, the emissions due to cars will also be reduced by the same percentage.

It should be noted that such one-for-one VMT replacement is only an approximation, especially in 1980 when electrics have a limited range and would be replacing second cars which account for a smaller fraction of the total VMT than their numbers indicate. Thus, as Hamilton[16] has shown, in 1980 replacing 17 percent of the conventional cars in the population affects only 11 percent of the VMT. For 1990 and 2000, the greater range of the electrics makes the one-for-one approximation more valid. A further complication is introduced by the presence of heavy-duty vehicles, assumed to contribute 5 percent of the VMT. In our analysis we have assumed that electrics do not replace heavy duty vehicles. Certainly, the one-for-one VMT reduction will yield air quality levels which represent the best we could possibly expect by substituting electrics for conventional vehicles. We can then interpolate between the baseline and upper limit air quality levels to estimate the effect of smaller changes in VMT. Linear interpolation should yield accurate estimates since, as we shall see, the perturbations in air quality levels are not large.

Using electric cars instead of conventional cars will reduce vehicular emissions, but will increase emissions from power plants. The latter effect is due to the recharging of batteries. This has been assumed to occur continuously throughout the day, with 90 percent of the total recharging load occurring between 11:00 p.m. and 9:00 a.m. and the remaining 10 percent spread uniformly over the period 9:00 a.m.-11:00 p.m. Figure 3.1 shows the resulting diurnal variation of power demand on the oil-fueled power plants in the study area under the upper bound electric car use for each year of interest. Table 3.2 shows the ratio of average electric power demand which would occur with electric cars to the baseline power demand shown in Table 2.2.

It has been determined in Ref. 13 that in 1980 and 1990, there will be sufficient electric power generating capacity in the South Coast Air Basin to accommodate the extra demand and that much of it will be borne

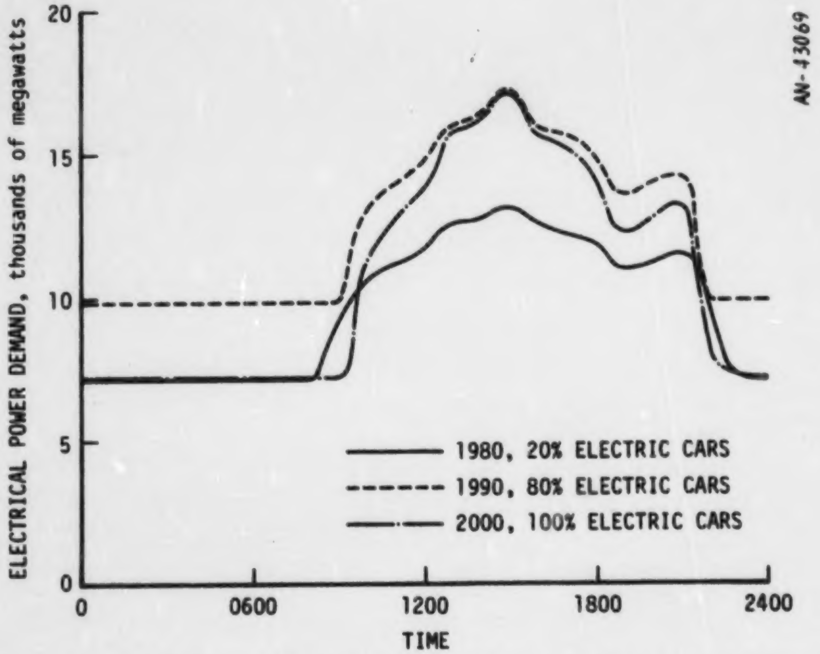

Figure 3.1. Projected Diurnal Power Demand on Oil Fired Power Plants in the Los Angeles Area for Peak Month (August)

TABLE 3.2

RATIO OF IN-BASIN ELECTRIC ENERGY DEMAND WITH ELECTRIC CARS TO BASELINE ENERGY DEMAND

1980	1990	2000
1.14	1.31	1.07

by oil-fired units.[1,13] By the year 2000, the power demand created by the postulated large number of electrics will be partly satisfied by power plants located outside the South Coast Air Basin.[13] As a result, the ratio shown in Table 3.2 for the year 2000 is lower than that for 1990, despite the fact that the number of electric vehicles has increased 40%, as can be seen in Table 3.1. Since power plants contribute negligible amounts to the hydrocarbon burden in the basin, we expect to see reductions in total hydrocarbon emissions, but this will be accompanied by increases in NO and SO_2 emissions.

Tables 3.3-3.6 illustrate the total basinwide emissions which would prevail with the use of electric cars. Table 3.7 shows the ratio of the

TABLE 3.3

1980 EMISSIONS WITH 20 PERCENT ELECTRIC CARS IN LOS ANGELES AND ENVIRONS (Tons/Day)

	NO	HC	CO	SO_2	Particulates
Vehicular	151.7	135.6	1898.8	18.3	80.6
Stationary Area Sources	106.0	160.7	--	195.3	96.9
Power Plants	129.2	--	--	412.7	14.4
Oil Refineries	48.8	33.7	--	60.6	11.0
TOTAL	435.7	330.0	1898.8	686.7	202.9

TABLE 3.4

1990 EMISSIONS WITH 80 PERCENT ELECTRIC CARS IN LOS ANGELES AND ENVIRONS

(Tons/Day)

	NO	HC	CO	SO_2	Particulates
Vehicular	33.8	33.6	798.0	6.7	53.0
Stationary Area Sources	140.8	160.7	--	213.1	105.7
Power Plants	152.2	--	--	487.3	16.9
Oil Refineries	53.7	37.1	--	66.7	12.2
TOTAL	380.5	231.4	798.0	773.8	187.8

TABLE 3.5

2000 EMISSIONS WITH 100 PERCENT ELECTRIC CARS IN LOS ANGELES AND ENVIRONS

(Tons/Day)

	NO	HC	CO	SO_2	Particulates
Vehicular	25.0	25.4	771.9	2.5	45.0
Stationary Area Sources	181.1	160.7	--	227.7	112.9
Power Plants	105.0	--	--	337.1	11.7
Oil Refineries	57.6	39.8	--	71.5	13.0
TOTAL	368.7	225.9	771.9	638.8	182.6

total emissions with electric cars to the total baseline emissions, the latter obtained from Tables 2.4-2.7.

The data in Tables 3.3-3.5 are graphically illustrated in Figs. 3.2-3.6. Figure 3.7 depicts the data for NO corresponding to Table 3.6 with auto emission controls delayed since only NO is significantly affected.

In all the graphs we have included data for 1970 to complete the emissions picture. In addition, in Fig. 3.7 we have included the effect of the higher automotive NO emissions to 1990 and 2000, even though no air quality calculations were carried out for these cases. The emissions data for these additional cases as well as for 1970 are found in Tables C.1-C.5 in Appendix C.

TABLE 3.6

1980 EMISSIONS WITH 20 PERCENT ELECTRIC CARS AND DELAYED IMPLEMENTATION OF EXHAUST EMISSION CONTROLS FOR CONVENTIONAL CARS IN LOS ANGELES AND ENVIRONS

	NO	HC	CO	SO_2	Particulates
Vehicular	247.1	142.2	1997.6	18.3	80.6
Stationary Area Sources	106.0	160.7	--	195.3	96.9
Power Plants	129.2	--	--	412.7	14.4
Oil Refineries	48.8	33.7	--	60.6	11.0
TOTAL	531.1	336.6	1997.6	686.7	202.9

TABLE 3.7

RATIO OF TOTAL EMISSIONS WITH ELECTRIC CARS TO BASELINE EMISSIONS

	Percent Electric Cars	NO	HC	CO	SO_2	Particulates
1980	20	0.97	0.93	0.86	1.07	0.96
1990	80	0.99	0.86	0.74	1.14	0.79
2000	100	0.88	0.81	0.67	1.07	0.80
1980d	20	0.93	0.93	0.86	1.07	0.96

Table 3.7 indicates that for NO, even massive amounts of electric cars on the road do not reduce the total emissions significantly, at best 12 percent. This is partly due to the increase in NO emissions from power plants, partly because of the increasing importance of emissions from other stationary sources, as is evident from Table 2.8 and Fig. 3.2, and also to the effect that heavy duty vehicles have on these emissions.

As shown in Table 3.7, the use of electric cars yields reductions in hydrocarbon emissions ranging from 7 to 19 percent. Here we see again the impact of the heavy duty vehicles, especially in the case of 100 percent electrics where trucks and buses contribute 9 percent of total hydrocarbon emissions.

For particulates, the emission reductions due to electric cars range from 4 to 21 percent. In this case there is not only the effect of heavy duty vehicles at work, but also the fact that about one-third of the particulate emissions from cars i[illegible] to tire wear (Ref. 15). Thus the vehicular component of particu[illegible]sions has a relatively large part which is unaffected by using electric cars.

Since CO is practically produced by vehicles alone, and is so considered in our study, the basinwide CO emissions are directly affected by the number of electric cars on the road. However, as indicated by Table 2.9, heavy duty vehicles account for between 29 to 67 percent of all CO emissions in 1980 and beyond. This is due to the stringent emission controls required for cars in contrast to the lack of attention which present laws pay to the control of heavy duty vehicle emissions. Consequently, large fractions of CO emissions are not affected by electric cars and the reductions induced by electrics are at best 33 percent and at worst 14 percent.

For SO_2, the picture is different. The increase in SO_2 emissions from power plants can be substantial, up to 14 percent. Thus the use of

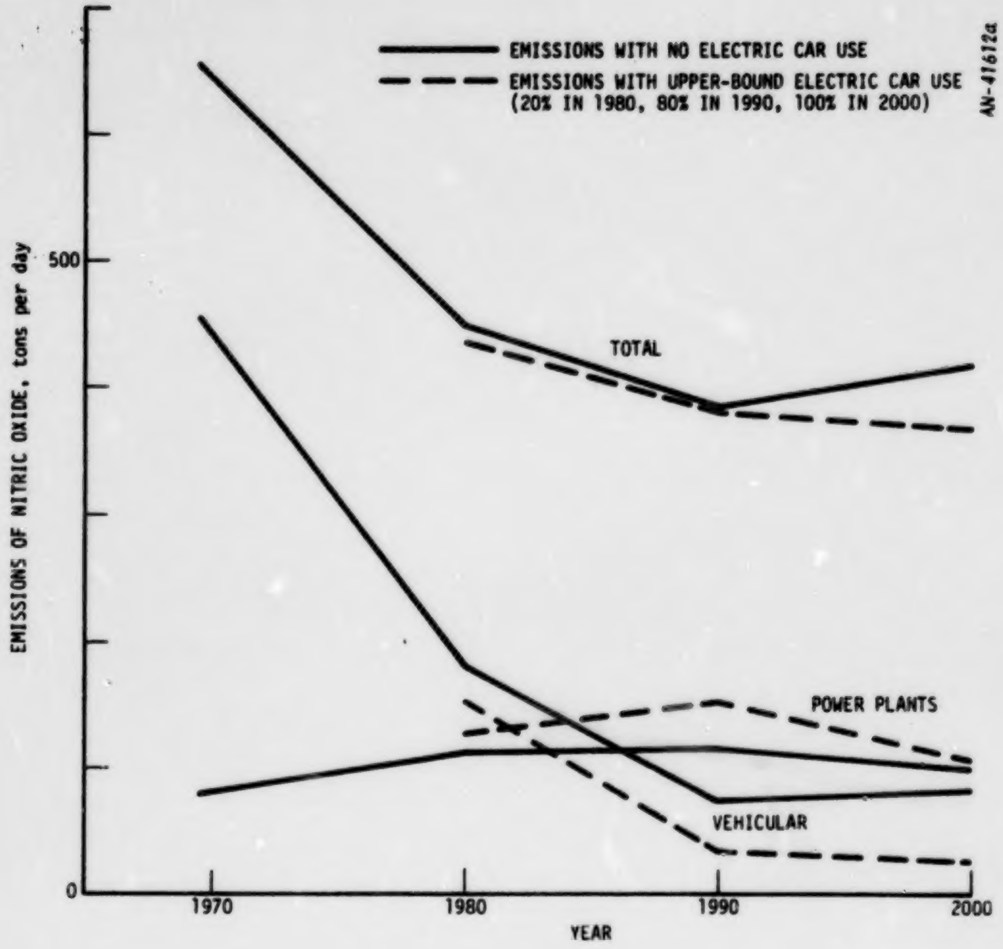

Figure 3.2. Plot of Nitric Oxide Emissions in Los Angeles and Environs Assuming No Delays in Auto Emission Controls

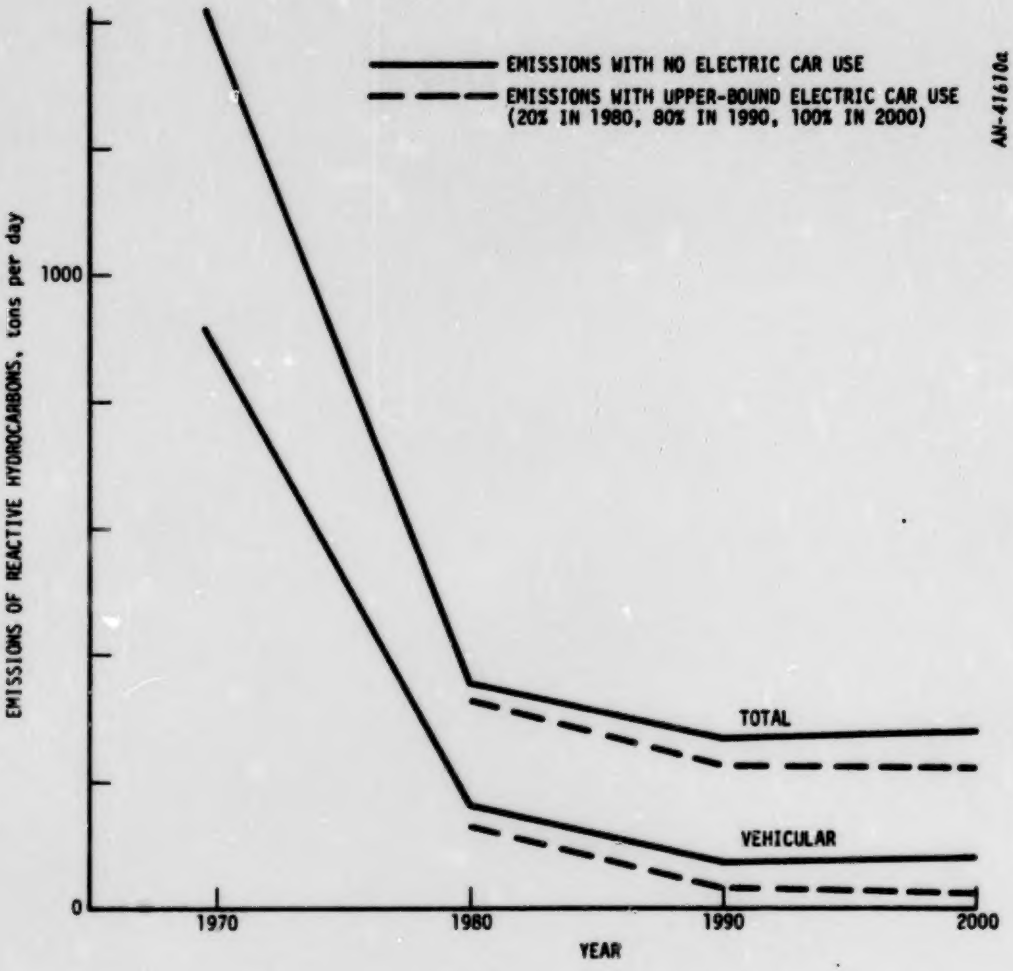

Figure 3.3. Plot of Reactive Hydrocarbon Emissions in Los Angeles and Environs Assuming No Delays in Auto Emission Controls

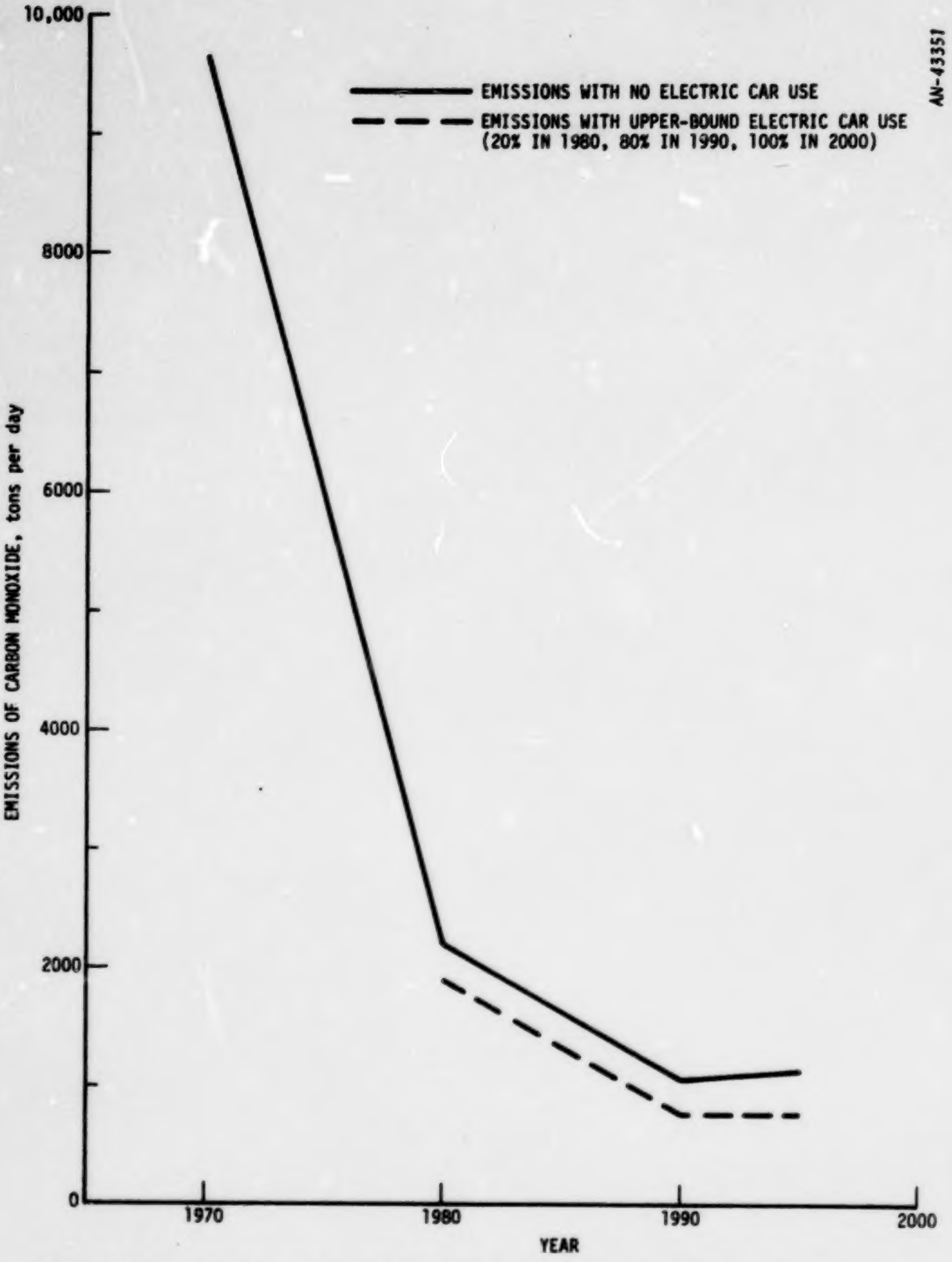

Figure 3.4. Carbon Monoxide Emission in Los Angeles and Environs Assuming No Delays in Auto Emission Controls

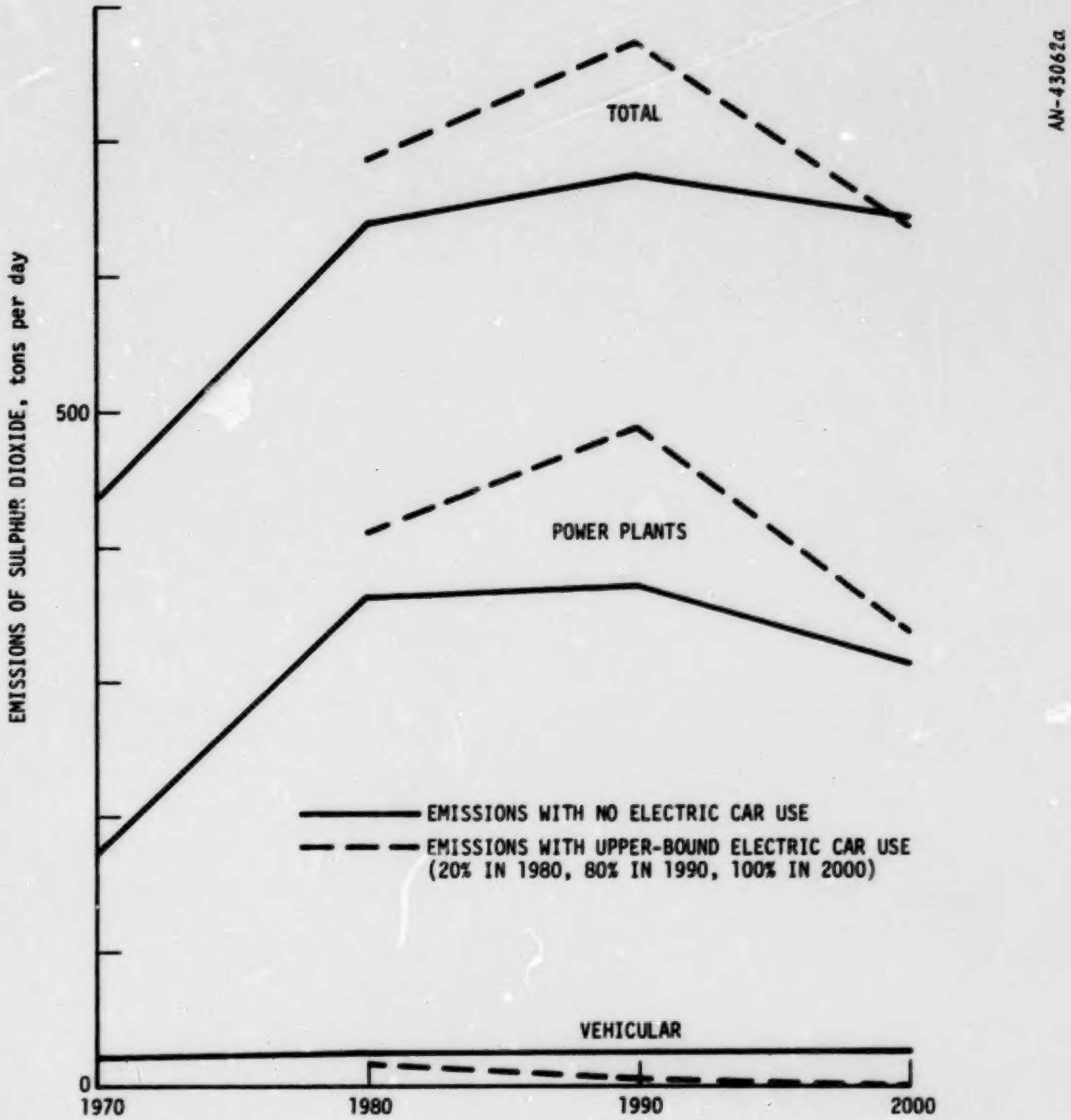

Figure 3.5. Sulfur Dioxide Emissions in Los Angeles and Environs

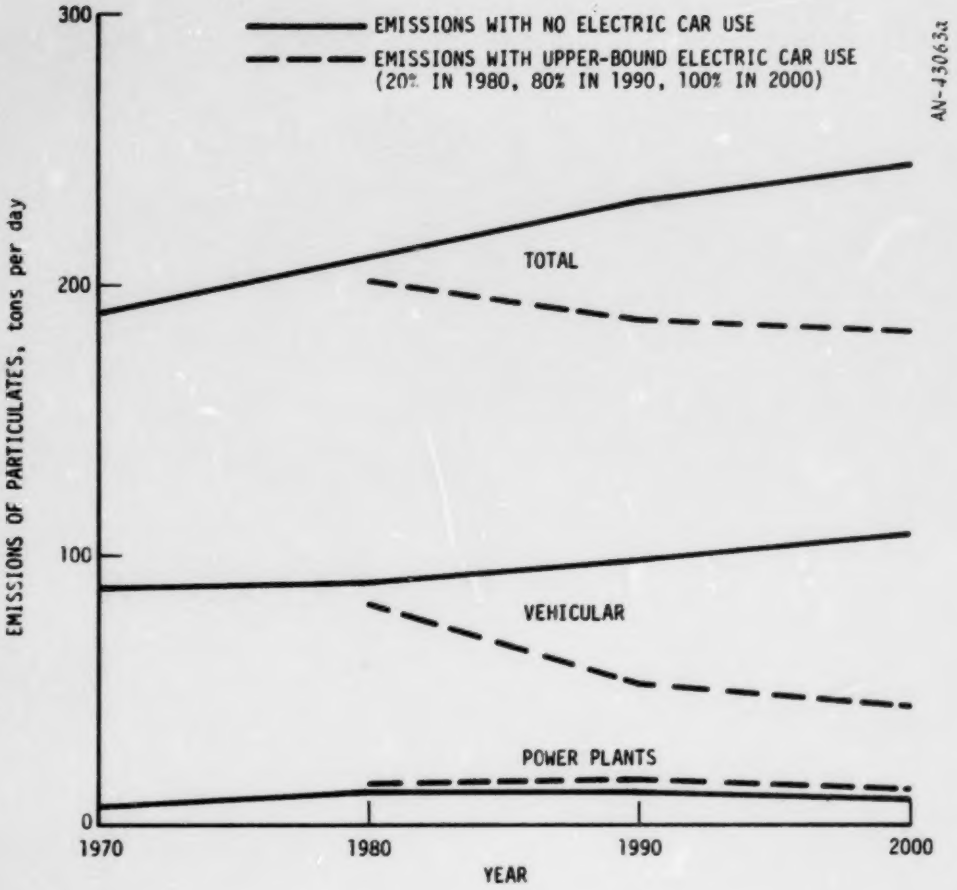

Figure 3.6. Particulate Emissions in Los Angeles and Environs

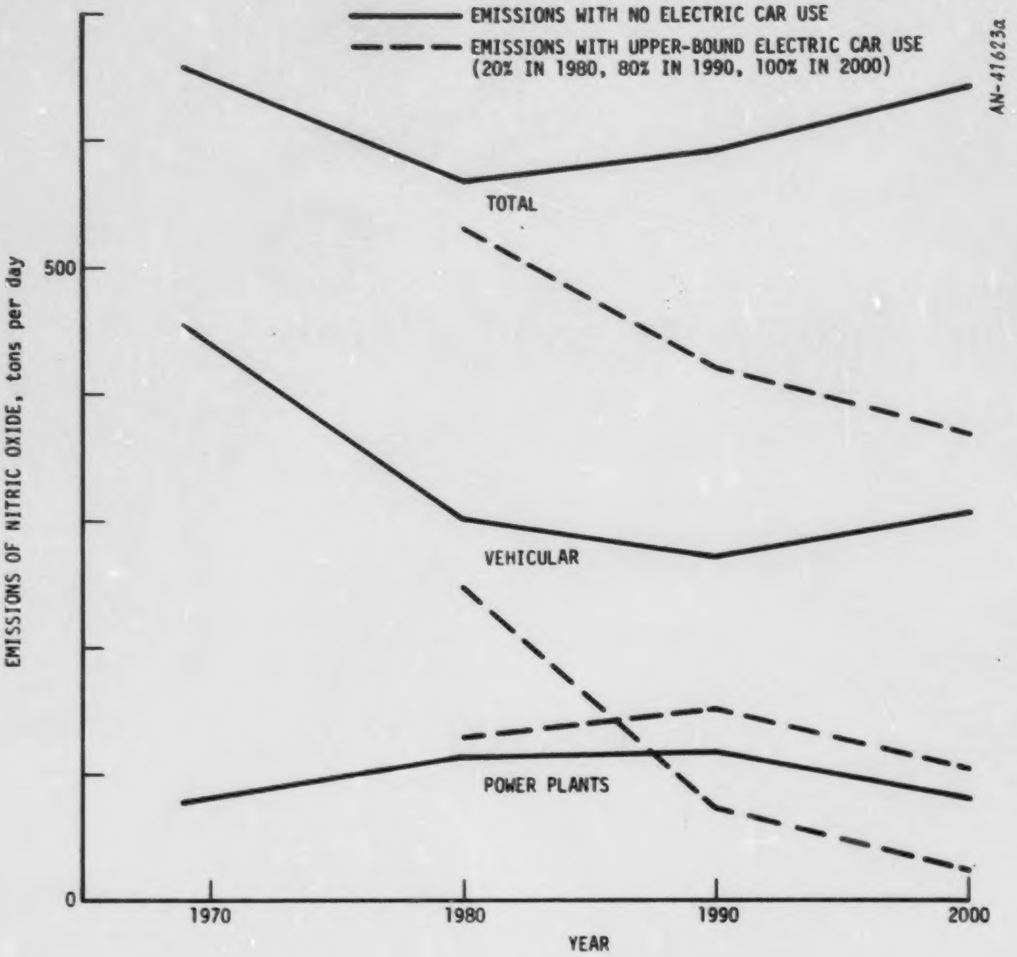

Figure 3.7. Total Nitric Oxide Emissions in Los Angeles and Environs Under Delayed Implementation of Auto Emission Controls

electric vehicles can increase atmospheric levels of SO_2 pollution. Consequently, it may be necessary to place more stringent controls on SO_2 emissions from power plants in order not to make matters worse.

Finally, the last row of Table 3.7 shows that for 1980, delaying the implementation of HC and CO controls for two years produces no perceptible changes from the case where controls are not delayed. For NO, on the other hand, the effect of the electric cars on the total emissions is greater in the delayed-control case because vehicular emissions play a larger role, thus giving electrics more leverage. This is clearly illustrated in Fig. 3.7. However, comparing Tables 3.3 and 3.6 we note that the absolute level of NO emissions is still almost 100 tons per day greater if the NO emission standard is frozen at 2.0 grams per mile instead of lowering it to 0.40 grams per mile as originally planned, even though electrics have a greater effect on a percentage basis.

Thus far, the discussion has focused on aggregated basinwide emissions. However, as might be expected, emissions have a great degree of spatial inhomogeneity. Hence the ratios shown in Table 3.7 do not necessarily represent the effects that might occur as air masses sweep over different parts of the region, thus receiving emissions from a diverse mix of sources. We have calculated the ratios of NO and HC emissions with electric cars to baseline emissions for each of the air trajectories used in the photochemical smog modeling task. (See Appendix B for maps of the air trajectories.) Table 3.8 shows the range spanned by these ratios. Table 3.8 indicates that in some instances in 1980 the ratio for total emissions approaches the ratio for vehicular sources. This is due, of course, to the air mass moving over areas of heavy traffic. In later years the maximum reductions fall far short of the vehicular ratios.

We note that the increases in NO emissions can sometimes be very high. This is accounted for by the presence of power plants along the route of the air mass, the increased emissions being due to the recharging of batteries. The excess NO will actually cause ozone concentrations to

TABLE 3.8

RATIOS OF HC AND NO EMISSIONS WITH ELECTRIC CARS TO BASELINE EMISSIONS FOR THE AIR TRAJECTORIES USED IN THE DIFKIN AIR QUALITY MODEL

	Vehicular		Range of Ratios for Total Emissions (Vehicular + Stationary)	
	NO	HC	NO	HC
1980	0.84	0.85	0.88-1.4	0.89-0.97
1990	0.45	0.46	0.72-3.1	0.72-0.96
2000	0.31	0.33	0.68-3.2	0.64-0.95
1980d	0.82	0.84	0.85-1.3	0.89-0.97

be reduced by virtue of the fast chemical reaction $NO + O_3 \rightarrow NO_2 + O_2$; thus when NO concentrations are high, the ozone is low and vice versa in a homogeneously mixed gas. Hence because of the excess NO, the ozone levels will be low in locations downwind of power plants.

3.3 AIR QUALITY AND ELECTRIC CAR USE

In this section we discuss the changes in pollutant concentration that may occur as a result of the use of electric cars. The DIFKIN air quality model was used for calculating concentrations of secondary pollutants NO_2 and ozone. Linear rollback was also used for ozone and NO_2, and exclusively for CO, SO_2, and particulates. Appendix D contains a brief description of the rollback formula and its use.

3.3.1 Effect of Electric Cars on Ozone

Table 3.9 contains the maximum hourly average ozone concentration for the baseline case obtained using the DIFKIN model and the rollback formula for the four cases of interest. The year 1970 was used as the reference year for the rollback calculation; the peak hourly ozone that year was 62 pphm (parts per hundred million) at Riverside. In 1970, the ambient air quality standard of 8 pphm hourly average not to be exceeded more than once a year was violated more than 1500 hours at Riverside. For the same year, the standard also was violated for more than 1500 hours at Azusa and

Pasadena. Downtown Los Angeles exceeded the standard for slightly over 600 hours and the San Fernando Valley localities of Burbank and Reseda showed violations for about 1100 hours. The peak hourly ozone values ranged from 33 pphm downtown to 58 pphm at Azusa. Thus in 1970, Riverside was afflicted with the worst ozone pollution, with Azusa a close second. The maximum ozone concentrations computed with the DIFKIN model also occur in the vicinity of Riverside and are shown in Table 3.9. The second highest computed ozone values occurred at Azusa and they were 11, 10, 9, and 7 for 1980, 1990, 2000, and 1980d, respectively. Maximum ozone levels computed elsewhere in the region were below the air quality standard and ranged from 3 to 7 pphm, the upper level occurring in the southeastern part of the basin and the low level occurring near Anaheim. The RMS error in the ozone concentrations computed using the DIFKIN model is 2 pphm.[5]

TABLE 3.9

BASELINE VALUES OF MAXIMUM HOURLY AVERAGE OZONE IN VICINITY OF RIVERSIDE (PARTS PER HUNDRED MILLION)

	DIFKIN Model	Rollback
1980	16	16
1990	15	13
2000	15	13
1980d	12	17

The predicted concentrations shown in Table 3.9 show that the rollback results are remarkably close to DIFKIN model estimates after rounding to the nearest integer. The most significant difference between the two methods of prediction is that, compared with the 1980 level, rollback predicts a higher value of ozone for the case 1980d, whereas the DIFKIN model predicts a lower value. The reason is that rollback, being based solely on hydrocarbon emissions, does not consider NO emissions and their potential for depressing ozone levels. Since hydrocarbon emissions are somewhat greater in the case 1980d than in 1980, the rollback formula predicts a slight increase in ozone. We believe that the DIFKIN model considers the effects of NO inhibition of ozone production whereas rollback does not. To be consistent, we will use the baseline concentrations obtained with the DIFKIN model to determine the effect of the electric cars. We note that in all cases shown in Table 3.9 the oxidant standard of 8 pphm is being violated. It is noteworthy that the state's own projections forecast a maximum hourly oxidant level of 12 pphm by 1980 using the linear rollback method.[17] The discrepancy between their estimate and ours is partly due to the different method of accounting for the reactivity of the hydrocarbons.

Table 3.10 shows the effect of the use of electric cars on the ozone level previously shown in Table 3.9. The results shown for the DIFKIN model use the DIFKIN model's predictions in both the numerator and denominator of the fraction. The rollback results were obtained by applying the linear rollback formula to the baseline concentration obtained with the DIFKIN model. From Table 3.10 it can be seen that electric cars

TABLE 3.10

RATIO OF MAXIMUM HOURLY AVERAGE OZONE
WITH ELECTRIC CARS TO BASELINE OZONE LEVEL

	Percent Electric Cars	DIFKIN Model	Rollback
1980	20	0.99	0.94
1990	80	0.90	0.88
2000	100	0.87	0.84
1980d	20	1.04	0.94

reduce the ozone level, but that the gains are relatively small compared with the reductions in vehicular emissions as reflected by linear rollback results. For the case 1980d, the DIFKIN model predicts a slight increase in peak hourly ozone when electric cars are in use. This is due to the differential removal of NO emissions along the trajectory of the air mass. In this case more NO than hydrocarbon was removed by the use of electric vehicles and this increased the ozone level. By contrast, for 1980 the two species were removed in almost equal amounts by using electrics and this caused the ozone to dip slightly. For 1990 and 2000, the substitution of electrics for conventional cars eliminated more hydrocarbon than NO and the ozone was reduced further. Note that in every case the rollback prediction overestimates the amount of the reduction in ozone level, although the difference is not large except for 1980d, where the rollback prediction is in the opposite direction from that of the DIFKIN model. In this instance we again see the deficiency in neglecting NO as a factor in ozone predictions using linear rollback. Also, the application of rollback uses the basinwide emissions rather than the emissions along the trajectory's path; this accounts for part of the discrepancy. It is noteworthy, however, that the rollback estimates shown in Table 3.10 are so close to the DIFKIN model's, although the difference in sign for the case 1980d can lead to seriously misleading conclusions. The closeness of the two estimates may be explained by the fact that we are working with very small perturbations in emissions; in this situation the difference between linear assumptions and the nonlinear character of the physical phenomena tends to be minimized. The two estimates are useful as upper and lower bounds on the possible effect of electric cars.

For Azusa, although no tables are shown in the text, the results obtained using the DIFKIN model indicate that the use of electric cars has imperceptible effects in 1980 and 1990. In the year 2000, the peak hourly ozone is reduced to 89 percent of its baseline value. The rollback estimates for Azusa essentially match those shown on Table 3.10 and thus overstate the effect of the electric cars at this receptor location. As was the case with Riverside, at Azusa we also obtained an increase in ozone concentration caused by the electric cars in the case 1980d; this time the increase is from 7 to 8 pphm or 14 percent. By contrast, rollback predicts a decrease as it did before.

Our results for other points in the region indicate that the effect of electric cars on ozone levels ranges from imperceptible to 50% reductions. We caution, however, that these large fractional reductions stem from the presence of low baseline concentrations. Hence small absolute differences can yield large percentage reductions and can be misleading. Since the ozone levels at these other points are already below the standard, further reductions are only of interest in establishing a margin of safety or in case the standard is lowered in the future, a move which is not currently contemplated.

We note that in no case are the reductions obtained with the electric cars sufficient to bring the ozone level into compliance with the air quality standard of 8 pphm in the vicinity of Riverside. The standard is predicted to be violated at Azusa as late as 1980 and 1990 even with electric cars. Thus other strategies besides electric cars are probably necessary to meet the standard. The electric cars will help, however, to reduce the number of times the standard is violated. Unfortunately, we cannot estimate the changes that would occur in the frequency of violations in the vicinity of Riverside because sufficient statistical air quality data for Riverside were not available to us. For Azusa the effect of the electrics in 1980 and 1990 is essentially imperceptible and thus no change in the frequency of violations can be expected. For the baseline case, in 1980 and 1990 we estimate that the oxidant standard at Azusa would be exceeded about 0.7 percent of the time, approximately 60 hours a year, compared with a frequency of violations ranging from 13 percent (∿1100 hrs) to 20 percent (∿1750 hrs) during the period 1965-1972. For the year 2000 the electric cars would reduce the frequency of violations from approximately 0.2 percent (∿18 hours) to 0.1 percent (∿9 hours).

Finally, we reiterate that, as our discussion has shown, the ozone concentration at other points in the air basin will be affected in diverse ways because of the spatial inhomogeneity of the emissions.

3.3.2 Effect of Electric Cars on NO_2

The results obtained for NO_2 with the DIFKIN model and with rollback for the baseline cases are shown in Table 3.11. The location where the maximum occurs is included because it varies for different years. As was done for ozone, the rollback calculations use 1970 as the reference year. In 1970 the maximum hourly NO_2 at Anaheim was 34 pphm and at Azusa it was 43 pphm. The corresponding annual average NO_2 in 1970 was 4.9 pphm at Anaheim and 6.3 pphm at Azusa. Since the air quality standard for NO_2 is 5 pphm annual average concentration, in 1970 the standard was barely met at Anaheim but exceeded at Azusa. The maximum hourly average NO_2

TABLE 3.11

MAXIMUM HOURLY NO_2 FOR BASELINE CASES

(pphm)

Year	Location	DIFKIN Model	Rollback
1980	Azusa	12	14
1990	Anaheim	10	13
2000	Anaheim	11	14
1980d	Azusa	13	17

shown in Table 3.11 under the rollback heading was obtained by taking into consideration the probability of occurrence of the maximum hourly NO_2 concentration which was actually observed. It can be seen in Table 3.11 that the rollback calculation yields concentrations greater than those obtained with the DIFKIN model. One possible reason for this difference is that rollback assumes the full conversion of NO to NO_2, a condition unlikely to be fulfilled if the hydrocarbon levels are low. Since future hydrocarbon emissions are greatly curtailed by various means of control, it is questionable whether all of the NO will be converted to NO_2, hence the discrepancy. The difference between the two predictions shown in Table 3.11 ranges from 16 to 30 percent but, in contrast with the ozone shown in Table 3.9, the baseline NO_2 predictions of DIFKIN and rollback are in phase in all cases. We should mention that the baseline rollback predictions indicate that the NO_2 air quality standard would be met in all but the 1980d case. By contrast, the NO_2 standard would be satisfied in all cases if we accept the DIFKIN model's predictions for the baseline case. Finally, we note that the maximum baseline NO_2 levels for 1980, 1990 and 2000 computed by the DIFKIN model at other points in the basin were in the range 5-10 pphm for all the cases.

The effect of the electric cars on the NO_2 concentrations is given in Table 3.12, where the figures shown are ratios of the maximum hourly NO_2 with electric cars to the baseline NO_2 level. Because the background NO_2 level is less than 1 pphm, it is inconsequential which of the two predicted baseline concentrations is used in the denominator for the rollback calculation. The reductions in concentration obtained by using electric cars which are implied by the ratios in Table 3.12 indicate that the NO_2 air quality standard will be satisfied in all cases, including the 1980d case with either prediction. The important point to note is that the NO_2 levels do not increase, in spite of the fact that NO emissions from power plants increase. The most likely explanation for this effect is provided by the fact that the use of electrics reduces hydrocarbon emissions, thereby lowering hydrocarbon concentrations and inhibiting the conversion of NO to NO_2. As might be expected, the rollback ratios match those shown for NO in Table 3.7.

TABLE 3.12

RATIO OF MAXIMUM HOURLY NO_2 CONCENTRATION WITH ELECTRIC CARS TO BASELINE NO_2 CONCENTRATION

Year	Percent Electric Cars	DIFKIN Model	Rollback
1980	20	0.92	0.97
1990	80	0.86	0.99
2000	100	0.88	0.88
1980d	20	0.92	0.93

We can also see in Table 3.12 that, compared with the DIFKIN model, the rollback predictions tend to underestimate the effect of the electric cars on NO_2. This is tantamount to saying that predicted NO_2 levels would be higher if the rollback forecasts are accepted, which was the same situation we saw in Table 3.11. Again, this can be partly explained by the failure of rollback to consider the control of hydrocarbons. It can be seen that the two ratios for the year 2000 are equal. For this year, the accuracy of the linear approximation is likely improved by the smallness of the perturbations in the emissions induced by the electric cars. For the case 1980d, the apparent 1 percent difference is probably not significant. The closeness of the two estimates for 1980d is likely due to the fact that the electric vehicles induce reductions in NO and hydrocarbon emissions of equal proportions, 93 percent, and thus the accuracy of the rollback method may be improved. We believe that the DIFKIN and rollback estimates provide bounds for the possible effects that using electric cars can have on NO_2 levels.

3.3.3 Effect of Electric Cars on Power Plant Emissions

Several air trajectories used in the air quality simulations contained power plants along their path. Our interest focuses on the emissions of nitric oxide from these plants since these greatly affect the formation of photochemical oxidants in general and ozone in particular. Table 3.13 shows the range spanned by the increases in nitric oxide emissions due to electric cars recharging for the air trajectories with power plants. These increases in nitric oxide coupled with decreases in hydrocarbon emissions along the trajectory inhibit photooxidation[18] and result in depressed ozone levels downwind of the power plant. These computed ozone concentrations are in the range 3-5 pphm, well below the standard. A related effect is that the decrease in hydrocarbon emissions also contributed to retarding the conversion of NO to NO_2, thus resulting in generally lower NO_2 concentrations or, if increased, only slight increases insufficient to augment ozone production through the photochemical cycle. However, we note that it is possible that for longer space and time scales than we considered, the ultimate NO_2 and ozone peaks may be higher.

TABLE 3.13

INCREASES IN NITRIC OXIDE EMISSIONS CAUSED BY ELECTRIC CAR BATTERY RECHARGE IN POWER PLANTS IN PATH OF AIR TRAJECTORIES

Year	Percent Increase
1980	5%-40%
1990	28%-205%
2000	33%-209%
1980d	2%-30%

Still unresolved, however, is whether the increased SO_2 emissions from power plants will act through synergistic or antagonistic mechanisms to enhance or suppress the production of ozone in the areas downwind of the power plants. Laboratory studies available in the literature indicate that SO_2 can inhibit or enhance oxidant formation depending on the concentration of water vapor and the kind of hydrocarbon which participates in the reaction.[19,20] These same studies also show that the maximum NO_2 concentration is always lowered by the presence of SO_2. However, the chemical mechanism for this effect is not well known. Basic theoretical knowledge is still insufficient in this area to enable us to resolve the problem of the effect of the increased SO_2 emissions from power plants on oxidant formation. It seems reasonable to conclude, however, that NO_2 concentrations will be generally lower at locations of the order 10-20 miles downwind of the power plant by virtue of the action of SO_2.

3.3.4 Effect of Electric Cars on SO_2, CO, and Particulates

These calculations were done using rollback exclusively with 1970 as the reference year. In 1970 the highest annual mean value of SO_2 was 2.6 pphm, the maximum hourly CO was 54 ppm (parts per million), and particulates were 357 $\mu g/m^3$, maximum 24-hr average. These concentrations occurred at Lennox, Reseda, and Anaheim, respectively, and were obtained from Ref. 20. The estimated baseline concentrations of these pollutants are given in Table 3.14. The SO_2 and particulate levels contained in Table 3.14 exceed the air quality standards and are the result of the projected baseline emission increases previously shown in Tables 2.4-2.6.

It should be noted that in 1970 the SO_2 air quality standard of 3 pphm annual arithmetic mean was not exceeded in the Los Angeles Basin, in spite of a high hourly maximum of 53 pphm which occurred at Lennox. For CO, on the other hand, the standard of 35 ppm hourly average was violated several times, but only once at the downtown monitoring station. By 1980 and beyond the CO standard would probably not be exceeded if the rollback calculations are even only moderately accurate and the exhaust emission controls are implemented on schedule.

TABLE 3.14

BASELINE MAXIMUM POLLUTANT CONCENTRATIONS ESTIMATED BY LINEAR ROLLBACK

	CO (ppm)*	SO_2 (pphm)**	Particulates ($\mu g/m^3$)†
1980	13	3.9	402
1990	7	4.1	437
2000	7	3.9	464
1980d	14	3.9	402

---

*Hourly average.

**Annual mean.

†24-hr average.

With electric cars in use, the effect is to reduce CO and particulates but to increase the SO_2 annual mean, as shown in Table 3.15. The ratios shown in Table 3.15 match those of Table 3.7, as might be expected in view of the relatively low background concentrations of these pollutants.

Since, as shown in Table 3.15, electric cars cause SO_2 to increase, the air quality standard for SO_2 would continue to be exceeded, assuming that the rollback calculations are accurate. In Los Angeles, the power plants tend to be concentrated along the coast and thus the receptors most heavily affected by SO_2 pollution are coastal communities downwind of the power plants. The data show, for example, that in 1970 locations such as Lennox and Long Beach had annual mean concentrations of 2.6 and 2.4 pphm respectively but that inland areas such as Azusa, Burbank, and Pasadena had mean concentrations of 1.8, 1.7, and 1.4 pphm, respectively. Thus areas such as Lennox and Long Beach will be hit hardest by SO_2 pollution which results from the use of electric cars.

The daily maximum value of particulate loading in 1970 occurred at Anaheim and was recorded at 357 $\mu g/m^3$ (Ref. 20). Loadings in the range of 300 $\mu g/m^3$ also occurred in Riverside. The ambient standard of 260

TABLE 3.15

RATIO OF POLLUTANT CONCENTRATION WITH ELECTRIC CARS TO BASELINE CONCENTRATION

	Percent Electric Cars	CO	SO_2	Particulates
1980	20	0.86	1.07	0.96
1990	80	0.74	1.14	0.79
2000	100	0.67	1.07	0.80
1980d	20	0.86	1.07	0.96

µg/m^3, 24-hr average, which is not to be exceeded more than once a year, was violated twice at Anaheim and once at Riverside in 1970. The aerosol in Los Angeles has been estimated to be composed of one-third natural background particles, one-third anthropogenic pollutants directly emitted into the atmosphere, and one-third chemically generated species produced by the presence of the anthropogenic sources.[21] This complex situation raises obvious reservations about the accuracy of the rollback formula when applied to particulate matter. With these reservations in mind, application of the rollback formula shows that the increase in primary particulate emissions that would occur in 1980-2000, shown in Tables 2.4-2.6, over the 1970 emissions would result in the higher particulate loadings indicated in Table 3.14. Thus the air quality standard for particulates would continue to be exceeded without electric cars. Using electric cars would reduce these maxima by the fractions shown in Table 3.15, but this is still not sufficient to satisfy the standard. However, the fact that photochemical activity would be reduced by the presence of electric cars implies that photochemical aerosol formation would decrease. At the same time, the increase in SO_2 emissions points to an increase in sulfate-based aerosols. What the net effect is has not been considered in the estimates. Since the rollback formula does not consider these complex interactions, and we know of no other presently available model which allows us to obtain a better estimate, we believe that the values quoted in Tables 3.14 and 3.15 are more representative of the component of the aerosols due directly to emissions rather than of the photochemically induced aerosols.

4 CONCLUSIONS

The baseline air quality estimates suggest that CO and NO_2 air quality standards will probably be satisfied in the Los Angeles area in the period 1980-2000 under presently contemplated emission control schedules for mobile and stationary sources. Recently proposed additional delays in the implementation of CO, NO_x, and HC controls for automobiles have only slight effects on air quality by 1980. For ozone, SO_2, and particulates, the baseline estimates indicate that the ambient air quality standards will likely be exceeded during 1980-2000, provided that present standards (or stricter ones) are in existence then.

In general, the substitution of electrics for conventional cars results in improvements in air quality for ozone, NO_2, CO, and particulates. For ozone and particulates, however, the improvements due to electric cars are insufficient to cause the ambient air quality standards to be met, although the frequency of the violations would be reduced. For NO_2 and CO, the improvements in air quality by electric car use are relative to atmospheric levels which are likely to satisfy the standards even without electric vehicles. Thus these beneficial results can be considered to increase the margin of safety for protecting the public health and welfare.

Because of the need to increase power generation for battery recharging, SO_2 levels will probably increase and result in violations of the current air quality standard for SO_2. This result for SO_2 was obtained under the assumption that emission controls for power plants continue to use present technology. Consequently, any new developments which lead to more effective control of SO_2 emissions will modify these results.

The results of the study suggest that electric cars, even in large numbers, cannot by themselves solve the air quality problems of the Los Angeles region. In the case of SO_2, they can actually make matters worse and cause standards to be exceeded where they would not be otherwise.

Part of the reason for the relatively low leverage of the electrics on air quality is that legislated automotive emission controls, if implemented on schedule, will decrease the vehicular contribution of the total air pollution burden (mobile + stationary). Hence the emissions reductions induced by electrics operate on an ever smaller fraction of total emissions. We should note that in the case of hydrocarbons, this effect is influenced by the fact that the fraction of hydrocarbon emissions from stationary sources considered to be reactive is based on a strict definition of reactivity and this tends to emphasize the contribution from stationary sources. Moreover, since emissions from heavy duty vehicles are relatively uncontrolled and no plans currently exist to reduce them further, the emissions from trucks and buses assume greater importance as those from passenger cars undergo substantial reductions. This further erodes the impact which electric vehicles might have on emissions and air quality. Spatial inhomogeneities in the distribution of sources, however, can produce significant improvements in localized areas. It seems appropriate, therefore, to consider the use of electric cars as one component of a wider strategy designed to improve the quality of the air, and thereby the quality of life, in the Los Angeles region.

We close with a word of caution regarding the interpretation of the results presented in this work since many uncertainties exist in the emissions data as well as in the air quality modeling procedures used. Our results have shown the air quality impact of electric cars to be small as regards photochemical oxidants and carbon monoxide. These results are influenced by two factors: the diminishing importance of automotive emissions with respect to stationary emissions (except for carbon monoxide); the large effect of emissions from relatively uncontrolled heavy duty vehicles. In the case of reactive hydrocarbons, the apparent lack of importance of automotive contributions is tied directly to the attribution of high reactivity to stationary hydrocarbon emissions, a subject which is now being debated by various governmental agencies. Should the reactivity of hydrocarbons from stationary sources be lower, the automotive contribution would increase, thus possibly increasing the impact of electrics. The leverage of electrics on air quality would be similarly increased if tighter emission controls are placed on heavy duty vehicles. However, it should be realized that further controls on heavy duty vehicles and on the reactivity of stationary hydrocarbons would result in better air quality without electric cars. Thus even though in these circumstances the relative impact of electrics would increase, their absolute impact on air quality would be marginal since they would be operating in a relatively clean environment.

APPENDIX A

POLLUTANT EMISSIONS ESTIMATES AND PROJECTIONS FOR THE LOS ANGELES REGION

A.1 INTRODUCTION

This appendix documents a pollutant source emissions model for most[*] of the South Coast Air Basin (SCAB) as assembled by GRC for use in air quality impact studies sponsored by the US Environmental Protection Agency (EPA) and the California Department of Transportation (CALTRANS). Since this emissions model is intended to provide input data for the GRC photochemical smog model (DIFKIN)[23] it must include specifications for the geographical and temporal distribution of pollutant emissions in the study area. As will be seen, detailed emission forecasts are based on available data for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x), the primary pollutants modeled in the DIFKIN code. The data available concerning SO_2 and particulate emissions are considerably less refined, but are included here to permit estimation of current and future regional emissions on a daily basis. Figure A.1 shows the region encompassed in this source model.[**] Within this 90-by-52-mile rectangle, emissions are aggregated in 2-by-2-mile squares and modulated by hourly time factors. All source locations cited in this appendix are measured with respect to the lower left-hand (southwest) corner of this rectangle, with x measured east and y measured north from that origin. Individual grid squares are identified by their I, J indices shown in Fig. A.1. The center of the rectangle (point 45.0, 26.0) is geographically located at

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[*] The portions of the SCAB in Santa Barbara and Ventura Counties, as well as some sparsely settled areas of Orange, Riverside and San Bernardino Counties are not currently included in the source emissions study area. A similar emissions model developed for the SCAB portion of Santa Barbara County is described in the body of this report.

[**] This region, referred to in this appendix as the "study area," is termed "Los Angeles and environs" elsewhere in the air quality analysis to distinguish it from the entire South Coast Air Basin.

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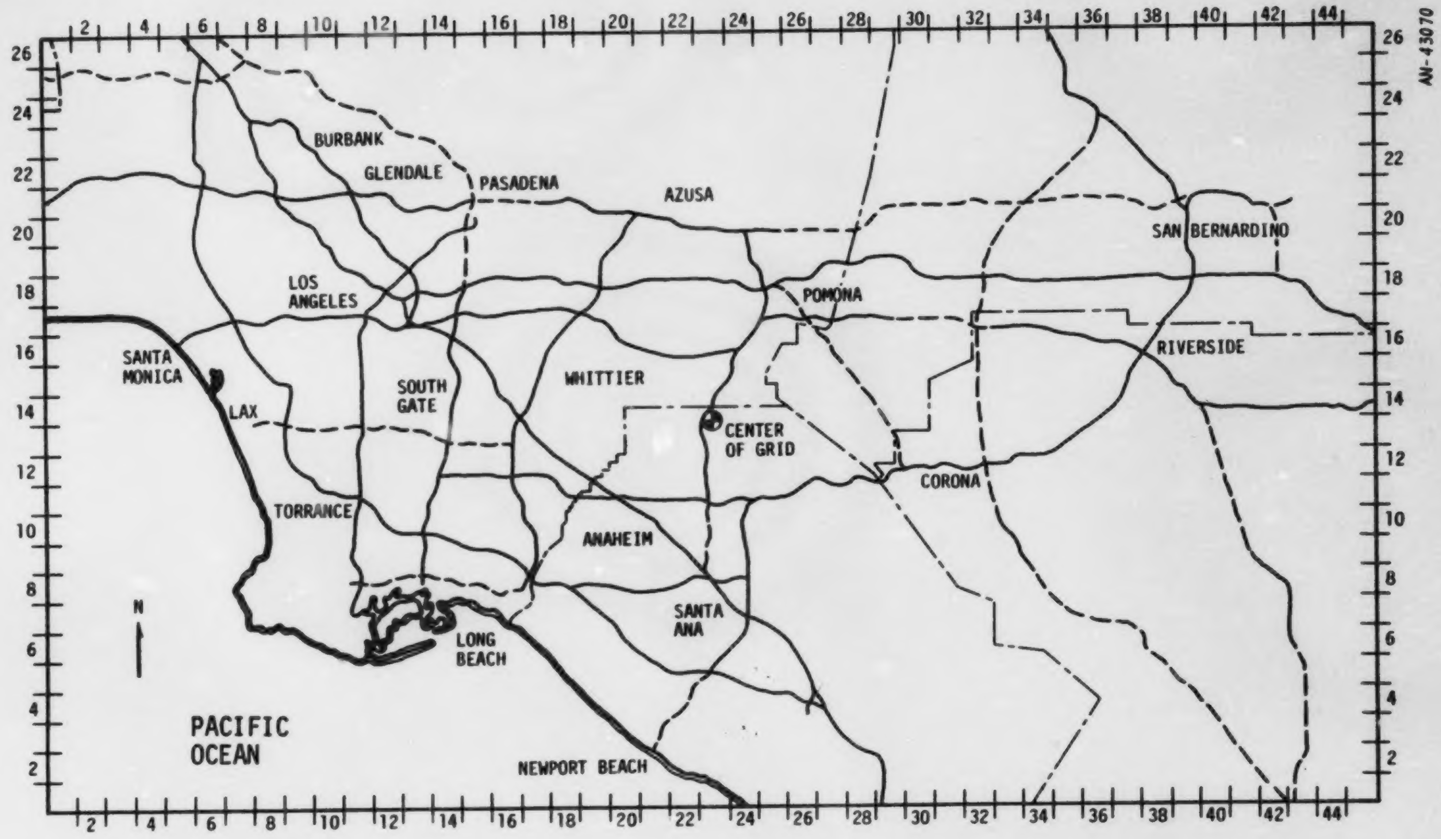

AN-43070
BURBANK
GLENDALE
PASADENA
AZUSA
SAN BERNARDINO
LOS ANGELES
POMONA
RIVERSIDE
SANTA MONICA
SOUTH GATE
WHITTIER
LAX
CENTER OF GRID
CORONA
TORRANCE
ANAHEIM
N
SANTA ANA
LONG BEACH
PACIFIC OCEAN
NEWPORT BEACH
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
2 4 6 8 10 12 14 16 18 20 22 24 26

Figure A.1. Emissions Model Study Area, Southern California (Los Angeles and Environs)

33° 55' 46.0" North latitude }
117° 52' 15.1" West longitude } Center of Study Area

which lies at the center of the northern edge of square 23, 13.

Motor vehicle emissions are calculated as the product of daily vehicle miles traveled (VMT) in each grid square times average vehicle emissions factors per mile of operation. Because vehicle emission factors vary considerably between stop-and-go and cruise-type driving, we separate the VMT in each square into freeway and surface street mileages. These VMT distributions and the methods used to derive them are described in Sec. A.2 of this appendix. Pollutant emission factors for an average unit of the California vehicle population were obtained using the method detailed in Ref. 11. Section A.3 outlines the assumptions and effects included in this method and presents graphs of the resulting vehicle emission factors for 1970, 1980, 1990, and 2000.

The GRC emissions model for the SCAB employs separate specifications of stationary point source emissions from power plants and oil refineries, and aggregates emissions from distributed stationary sources (e.g., gasoline marketing, dry cleaning, organic solvents uses, etc.) by grid square. Each of the three stationary source types has its own diurnal time distribution which determines the fraction of total daily emissions occurring in each hour of the day. Sections A.4, A.5, and A.6 describe the procedures employed in predicting daily emissions of HC and NO_x from these three source categories, and their spatial and temporal distributions. Stationary source emissions of CO may be safely neglected since they contribute about 0.1 percent of the total daily CO burden in the L.A. Basin.[12]

Public Policy in the area of pollution control plays an important role in the prediction of future emissions inventories. In the South Coast Air Basin, Federal, State, and County regulations all impact the forecasting process. While the EPA has generally preempted the area of motor vehicle emission control, it has on occasion yielded in favor of more stringent controls promulgated by the California State Air Resources Board (ARB). The schedule of Federal and State standards limiting pollutant emissions from new motor vehicles in California is tabulated in Sec. A.3. Rules set up by the Los Angeles County Air Pollution Control District (LACAPCD) prescribe limits on emissions from existing and newly constructed power generating units. These regulations, which served to guide our projections of power plant emissions in future years, are included in Sec. A.4. Finally, as required by the Federal Clean Air Amendments of 1970, California has proposed a set of emission control regulations designed to reduce significantly the emissions from mobile and stationary sources. This plan, known as the State Implementation Plan (SIP),[17] has its major impact in the area of hydrocarbon emissions from stationary sources. We have employed Revision 4 of the SIP here, and our assumptions regarding its application and effectiveness are outlined in Sec. A.6.

Following conventional practice, we have reported all NO_x emissions in this Appendix as NO_2, and, where necessary, have assumed that our data sources have done likewise. Since, in fact, essentially all emissions of NO_x are nitric oxide (NO), the NO_x emissions reported here may be converted to NO by multiplying by 30/46.

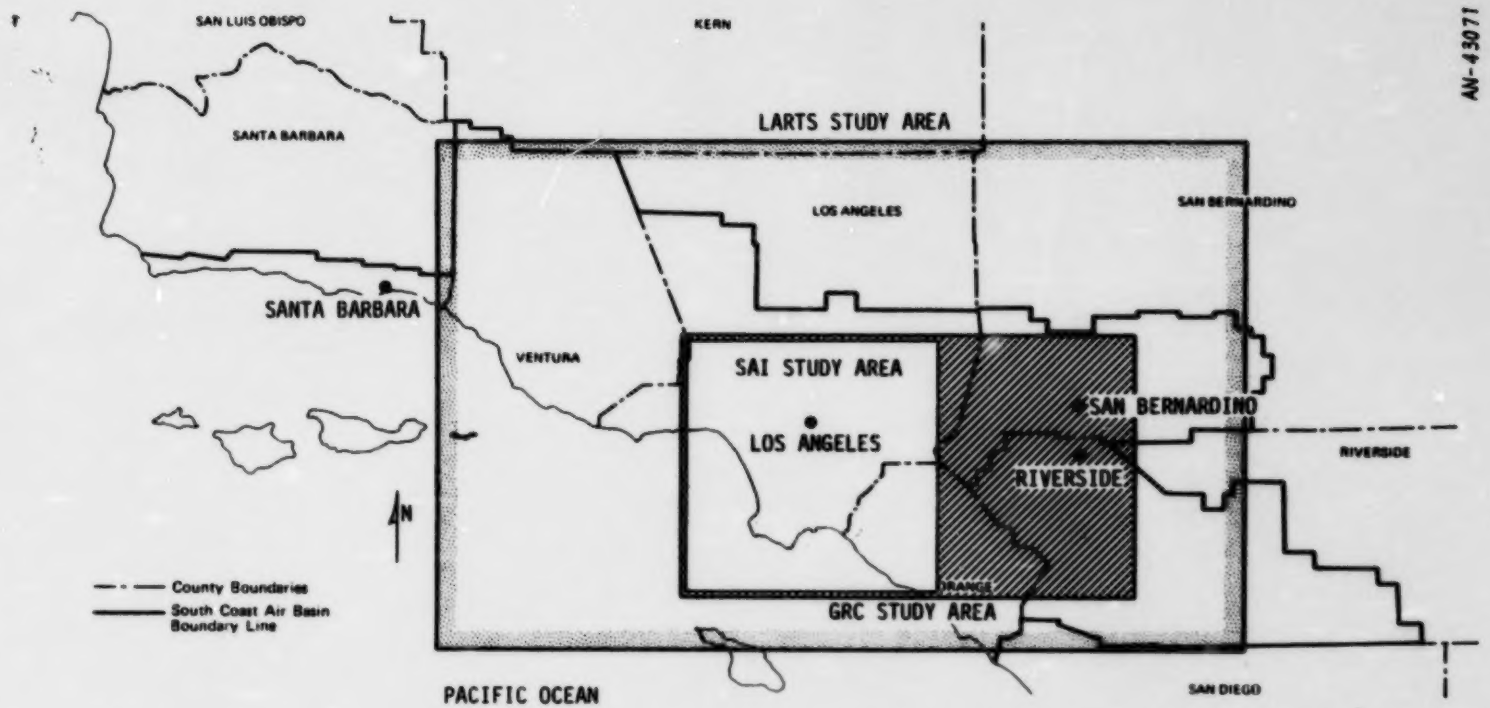
A.2 ESTIMATION AND PROJECTION OF VMT AND AVERAGE SPEED DISTRIBUTIONS

Our VMT distributions are based on traffic data from two sources, the VMT data collected by Systems Applications, Inc. (SAI)[24] in 1968 as part of their development of an emissions model for the Los Angeles Basin, and VMT data for the SCAB at a future population of 16.1 million people, supplied by the California Department of Transportation, District 07. These latter data were derived from the results of a network flow simulation performed by the Los Angeles Regional Transportation Study (LARTS) by allocating network link mileages or portions thereof to grid squares and multiplying by the corresponding average daily traffic on each link as predicted by the network flow model. The network simulated by LARTS included all planned freeways in the region for which construction funds have been authorized, such as the Century Freeway (Rte 105) and the Long Beach Freeway Extension (Rte 7).

As can be seen in Fig. A.2, the LARTS study area encompasses most of the SCAB with the exception of the portion in Santa Barbara County and the sparsely populated eastern end of Riverside County. The inner square (50-by-50 miles) is the area included in the SAI model. The grid selected for our current emissions model extends the SAI study area east to include the Riverside-San Bernardino area as shown by the shading in Fig. A.2.

In companion reports to this one, Hamilton and Houser[6,7] have made projections of transportation usage and population in the SCAB for the years 1980-2000. The results of these studies indicate that the LARTS vehicle population and usage estimates leading to the VMT data mentioned above must now be considered high. To obtain estimates of VMT distributions for future years and populations, we have chosen to interpolate between the data reported by SAI (c. 1968) and the VMT derived from the LARTS simulations, using total SCAB VMT reported in Ref. 7 as the scaling parameter.

Before the interpolation process could begin, however, it was necessary to resolve two data base problems: first, the existing 1968 data had to be transferred from the SAI grid to the CALTRANS grid, which is unfortunately shifted one mile in each coordinate, and second, no 1968 VMT data existed for the portions of the expanded study area outside the SAI grid. The data transfer method used allocates the mileages in each SAI grid square to the four surrounding new grid squares in proportion to the CALTRANS mileages in the new squares. (Freeways not in existence in 1968 are temporarily deleted from the CALTRANS VMT grid during the mileage allocation process.) This method preserves total VMT and avoids putting mileage into squares where none should exist. Separate data transfers were performed for freeway and surface-street VMT. The remaining grid squares in the expanded study area were filled with 1968 VMT by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SAN LUIS OBISPO
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LARTS STUDY AREA
SANTA BARBARA
LOS ANGELES
SAN BERNARDINO
SANTA BARBARA
VENTURA
SAI STUDY AREA
LOS ANGELES
SAN BERNARDINO
RIVERSIDE
RIVERSIDE
ORANGE
GRC STUDY AREA
N
County Boundaries
South Coast Air Basin Boundary Line
PACIFIC OCEAN
SAN DIEGO

Figure A.2. VMT Study Areas in Southern California

scaling down the CALTRANS VMT (without future freeways) in proportion to total SCAB VMT. As was mentioned earlier, the CALTRANS VMT was derived from a LARTS model run for a SCAB population of 16.1 million. Associating this population with the year 2000 (under Department of Finance Series D-150 projections for the SCAB) permits us to use per capita vehicle ownership and average annual mileage data from Ref. 7 to estimate the corresponding total annual SCAB VMT at 120.5 billion miles. Comparing this figure with a 1968 total annual VMT of 45.9 billion in the same region, we concluded that the CALTRANS VMT should be divided by 2.62 to arrive at equivalent 1968 mileages.

Figure A.3 plots our best estimate of SCAB VMT growth from 1968 to 2000 as derived in Ref. 7. With the 1968 distributions of daily freeway and surface street VMT filled in on the expanded grid, VMT distributions

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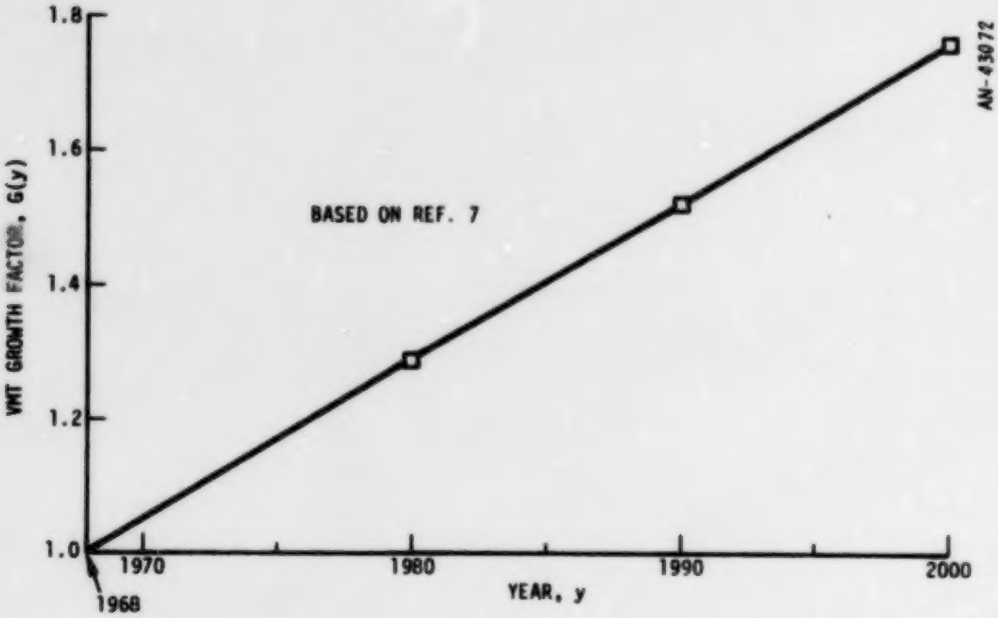

Figure A.3. Estimated Total VMT Growth Factors for the South Coast Air Basin

for intermediate years are calculated on a square-by-square basis for each category as

$$M_3 = M_1 + \frac{G(y) - 1}{2.62 - 1} (M_2 - M_1)$$

where y = desired target year
$G(y)$ = VMT Growth Factor for year y from Fig. A.3
M_1 = 1968 VMT
M_2 = CALTRANS VMT (SCAB population = 16.1×10^6)
M_3 = VMT for year y

This formula scales down the VMT in each square from the 16.1 million population value to a value corresponding to the growth curve in Fig. A.3. Figures A.4 through A.9 show the resulting maps of daily freeway and surface street VMT for the years 1970, 1980, and 2000.

In developing their vehicular emissions model for the Los Angeles Basin, SAI[24] was able to show that only small local errors (<11 percent in the daytime hours) resulted from the use of a single average time distribution each for freeway and surface street traffic volumes. In the absence of new temporal distribution data for either the SAI or extended grids, we are employing those derived by SAI and plotted here in Fig. A.10. Table A.1 lists the hourly traffic volumes on freeways and surface streets expressed as fractions of the average daily VMT occurring in each one-hour time period.

The vehicular emissions model in Ref. 24 also included relatively detailed data on average freeway traffic speeds for each direction of flow in each grid square on an hourly basis during the morning traffic peak, 6:00-10:00 a.m. Lacking information of comparable geographic detail for the expanded portions of the grid, or for future years, we elected to use average freeway traffic speeds in each direction over the whole grid

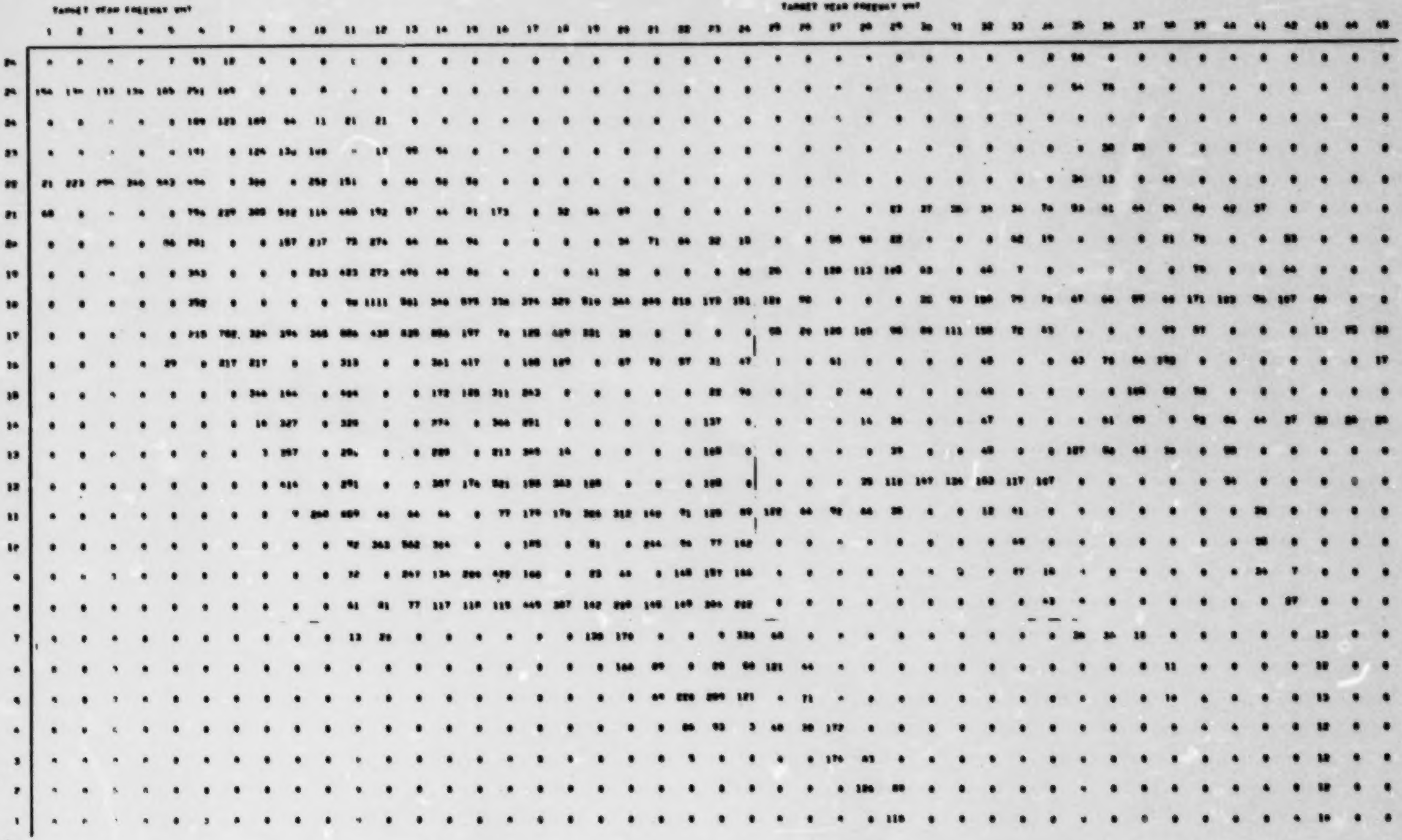
TARGET YEAR FREEWAY VMT
TARGET YEAR FREEWAY VMT

Figure A.4. Geographical Distribution of Freeway VMT in 1970, Thousands of Miles

TARGET YEAR SURFACE STREET VMT

TARGET YEAR SURFACE STREET VMT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
26	0	4	0	0	56	41	114	10	5	0	1	0	0	1	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
25	17	70	96	161	244	246	165	163	52	52	47	0	0	4	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
24	32	153	136	200	231	317	261	211	146	17	56	139	0	0	0	4	2	0	0	0	0	0	1	2	0	0	0	0	5	1	0	0	0	0	0	0	0	0	19	10	0	10	5	2	0
23	62	292	269	357	279	130	201	141	104	61	6	47	150	51	16	0	0	0	0	0	0	0	3	0	0	0	0	0	5	0	0	0	0	0	0	7	9	0	0	19	0	0	0	32	14
22	96	281	206	260	82	350	443	346	344	351	164	29	98	33	229	126	15	9	0	0	0	1	2	0	0	0	0	0	5	0	0	0	0	0	2	1	1	13	2	23	0	0	31	20	0
21	50	25	33	46	88	173	189	177	216	66	86	441	167	41	291	355	269	255	168	99	21	38	51	26	24	0	0	4	17	0	1	7	10	9	10	16	12	22	36	67	43	0	10	0	0
20	1	0	0	0	0	22	49	79	149	137	170	306	144	186	257	145	260	264	170	96	79	266	199	126	72	32	45	42	82	43	27	7	11	3	36	41	41	46	140	95	92	30	18	2	0
19	9	37	0	0	0	43	116	267	621	701	326	140	123	113	305	349	276	254	133	[illegible]	176	310	[illegible]	46	71	76	93	54	78	56	36	10	27	32	70	96	60	92	90	62	30	14	39	0	3
18	0	14	19	18	77	297	503	621	503	526	691	796	265	188	193	195	148	265	206	170	231	186	51	29	29	96	96	81	60	67	18	3	12	60	31	16	57	36	64	58	16	37	76	20	13
17	19	48	67	138	271	477	355	261	458	412	376	727	363	264	286	169	83	77	36	173	219	62	44	35	55	19	53	78	42	24	38	24	17	6	0	13	42	21	26	1	0	16	35	12	30
16	0	0	0	0	156	270	356	227	237	529	369	536	290	171	286	250	253	74	0	93	92	87	95	26	7	0	9	26	14	5	12	0	30	59	36	61	60	30	3	0	1	0	12	0	1
15	0	0	0	0	0	86	265	312	440	376	495	353	350	314	272	267	232	277	47	82	14	52	34	29	0	2	15	16	2	0	12	15	7	16	66	26	115	73	12	0	0	1	0	7	0
14	0	0	0	0	0	1	92	322	373	372	360	186	410	253	321	345	144	184	259	172	116	47	26	0	4	4	0	0	0	4	0	36	10	36	69	94	61	30	1	0	12	0	12	0	0
13	0	0	0	0	0	0	50	273	347	350	235	275	342	227	319	376	313	236	224	97	157	216	82	65	4	6	0	0	4	0	17	20	0	56	96	27	11	21	7	27	17	3	0	4	0
12	0	0	0	0	0	0	25	264	374	402	239	265	295	218	298	210	167	112	173	183	195	81	126	72	56	1	0	5	15	13	42	41	11	16	22	16	11	21	7	21	0	0	0	1	0
11	0	0	0	0	0	0	0	107	380	276	198	77	93	406	384	292	56	124	363	142	412	245	157	63	32	4	52	16	5	0	0	39	2	0	4	0	1	4	6	0	16	5	4	1	0
10	0	0	0	0	0	0	0	68	496	300	145	68	115	264	191	291	178	179	196	252	294	329	90	81	20	6	24	0	0	0	0	2	11	4	2	1	1	2	1	14	11	5	2	6	0
9	0	0	0	0	0	0	0	43	239	374	353	285	186	437	299	215	128	144	197	252	191	267	135	208	91	9	4	0	0	0	0	0	1	2	0	0	0	0	0	3	18	0	1	1	1
8	0	0	0	0	0	0	14	49	123	93	170	111	122	368	296	293	103	83	157	211	288	273	191	174	41	5	16	7	0	0	0	0	0	0	1	0	0	0	0	4	29	19	1	0	0
7	0	0	0	0	0	0	0	22	21	85	212	10	0	0	[illegible]	96	41	90	109	176	105	231	272	170	147	14	3	7	0	4	0	0	0	0	2	7	12	0	0	0	0	19	27	23	29
6	0	0	0	0	0	0	0	0	5	15	115	0	0	0	0	0	33	66	133	134	109	117	105	63	43	10	36	4	1	2	0	0	1	0	0	0	14	15	7	1	4	14	0	0	4
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	51	229	144	189	104	22	25	19	24	3	0	4	2	0	0	0	0	0	0	19	10	4	5	10	4	1	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	88	129	294	122	114	16	5	17	52	58	12	9	0	0	0	0	3	12	4	15	15	2	0	5	3	2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	109	322	136	11	4	0	73	78	52	24	1	0	0	0	1	5	0	4	6	35	10	0	2	0	5
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	12	147	19	2	1	32	79	100	37	12	0	3	4	5	0	0	0	0	4	25	0	2	3	2
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	4	4	27	40	62	7	3	3	1	0	0	0	0	0	0	0	4	27	0	0	0

Figure A.5. Geographical Distribution of Surface Street VMT in 1970, Thousands of Miles

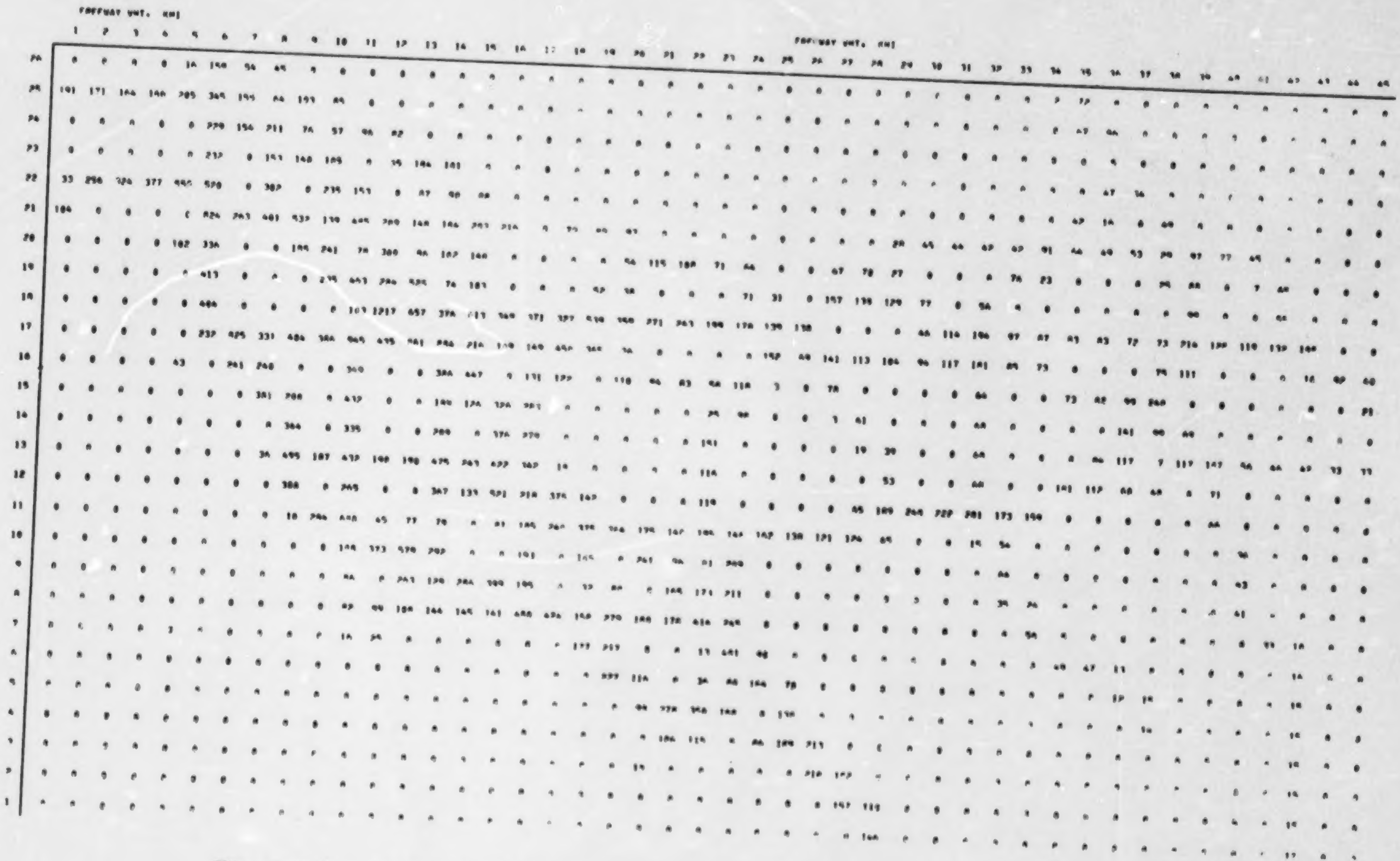

Figure A.6. Geographical Distribution of Freeway VMT in 1980, Thousands of Miles

SURFACE STREET VMT, KMI

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
26	0	7	0	0	44	58	150	17	0	0	2	2	2	4	7	5	0	0	0	0	0	0	0	2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0
25	21	41	47	158	267	252	192	192	38	81	48	0	0	0	4	3	0	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	2	11	1	4
24	40	192	126	197	234	375	244	216	160	16	52	143	0	12	0	0	3	0	0	0	0	0	2	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	23	10	11	11	4	2	0
23	72	291	264	341	281	334	276	130	190	49	6	44	152	98	10	0	0	0	0	0	0	0	4	0	0	0	2	0	4	0	0	0	0	0	6	3	11	0	0	24	0	2	0	30	17
22	101	280	214	265	80	351	413	335	340	351	145	21	101	37	248	130	16	1	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	3	1	1	16	2	20	0	4	38	24	0
21	75	25	33	46	98	194	193	198	219	48	98	458	181	45	414	350	244	254	149	103	22	40	94	28	30	0	0	5	21	0	1	9	17	11	22	20	15	27	44	107	43	14	19	4	0
20	2	6	0	0	0	22	44	87	153	169	198	329	152	198	278	170	282	260	149	94	78	244	195	133	70	42	56	51	188	52	33	9	14	4	17	91	50	57	173	117	44	41	15	2	0
19	27	42	0	0	0	42	126	274	453	737	364	144	132	114	314	344	287	282	134	143	175	310	191	42	23	95	115	60	97	69	44	12	33	39	94	69	74	63	113	74	13	18	34	0	3
18	0	16	22	23	80	310	422	484	535	562	748	849	274	166	188	190	102	270	214	191	240	197	54	31	33	116	110	90	100	82	22	3	19	25	30	20	70	44	70	72	19	44	91	32	10
17	28	59	84	142	281	499	376	270	484	438	344	779	377	229	293	148	91	82	40	104	220	73	54	37	63	31	44	80	52	38	30	20	21	0	0	14	50	24	32	1	0	10	30	14	37
16	0	0	0	0	145	282	385	239	252	544	373	549	388	173	280	268	274	81	0	104	90	97	60	38	10	0	12	32	18	6	14	10	40	72	43	74	74	34	3	0	1	2	15	4	1
15	0	0	0	0	0	92	199	316	454	394	413	354	381	321	278	279	253	294	52	90	10	64	30	35	0	3	18	18	3	0	14	19	0	19	53	12	141	90	15	0	0	1	11	0	4
14	0	0	0	0	0	3	95	315	373	368	349	185	457	244	321	314	152	170	244	180	130	40	32	0	4	4	0	0	11	5	9	45	21	47	44	115	75	25	1	0	15	4	15	2	0
13	0	0	0	0	0	0	44	253	344	335	207	294	355	234	310	340	341	287	282	105	171	237	91	82	4	0	0	0	4	9	21	25	0	71	111	33	14	34	0	33	20	3	7	5	0
12	0	3	0	0	0	0	27	251	373	391	235	214	381	210	312	220	143	124	188	112	215	86	132	84	76	2	0	4	14	13	50	50	13	21	20	13	13	24	0	25	0	0	0	1	0
11	0	0	0	0	0	0	0	187	383	274	198	81	99	412	354	244	65	130	319	144	429	251	154	70	63	2	61	0	4	0	0	40	2	0	4	0	1	4	7	9	18	4	4	1	0
10	0	0	0	0	0	0	0	72	450	393	148	71	120	271	189	288	187	180	190	255	381	124	144	82	40	16	27	0	0	2	0	2	13	4	3	1	1	1	1	17	14	4	2	7	10
9	0	0	0	0	0	0	1	43	238	379	353	244	185	435	290	217	134	157	283	258	190	312	167	238	103	17	0	0	2	2	0	0	1	2	0	0	0	0	0	4	22	4	1	1	2
8	0	0	0	0	0	0	14	68	131	54	173	180	175	362	293	282	187	90	182	215	248	294	100	176	44	0	18	0	0	0	0	0	0	7	1	0	0	0	0	0	24	23	1	0	1
7	0	0	4	0	0	2	0	21	23	84	203	17	0	0	0	48	41	44	103	170	176	244	277	172	120	27	3	0	11	7	0	0	0	0	2	3	14	0	0	4	0	23	34	20	24
6	0	0	0	0	0	0	0	0	4	17	171	2	0	0	0	0	23	40	144	140	117	128	204	73	42	47	45	0	1	2	0	0	1	0	0	0	14	19	0	1	4	17	0	0	4
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	52	234	191	195	114	24	49	41	33	3	0	4	2	0	4	0	0	2	10	23	22	0	4	13	4	1	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	30	80	120	294	132	144	35	17	21	44	71	15	11	0	2	0	0	4	15	4	10	10	3	11	4	3	3
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	14	107	314	144	14	18	3	94	47	64	30	1	0	0	0	1	4	0	4	7	41	12	[illegible]	2	0	4
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	11	193	22	4	3	40	47	121	64	15	0	4	4	4	2	0	0	0	0	31	2	2	0	3
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	40	18	3	24	154	24	2	3	4	1	0	0	0	0	0	0	0	4	34	0	4	4

Figure A.7. Geographical Distribution of Surface Street VMT in 1980, Thousands of Miles

FREEWAY VMT, KM

FREEWAY VMT, KM

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
26	0	0	0	0	35	301	74	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	40	0	0	0	0	0	0	0	0	0	0
25	167	233	236	226	270	510	252	87	141	116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	137	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	301	225	276	107	77	131	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	313	0	193	170	123	0	40	251	130	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	67	0	0	0	0	0	0	0	0
22	95	319	381	436	588	570	0	309	0	265	148	0	119	123	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	27	0	67	0	11	0	0	0	0	0
21	173	0	0	0	0	476	313	432	580	150	535	248	326	230	434	204	0	170	156	140	0	0	0	0	0	0	0	0	30	67	48	58	58	126	40	47	72	40	133	108	42	0	0	0	0
20	0	0	0	0	134	449	0	0	240	307	92	335	118	136	226	0	0	0	0	96	208	193	147	197	0	0	92	96	37	0	0	0	103	32	0	0	0	36	120	0	0	88	0	0	0
19	0	0	0	0	0	511	0	0	0	290	535	313	591	85	161	0	0	0	71	52	0	0	0	82	99	0	216	174	175	105	0	77	11	0	0	0	0	0	128	0	0	94	0	0	0
18	0	0	0	0	0	507	0	0	0	0	111	1402	484	432	671	370	307	320	573	387	312	291	240	292	175	215	0	0	0	43	155	205	133	118	113	113	90	90	250	176	142	181	167	0	0
17	0	0	0	0	0	269	988	360	427	435	1056	457	923	941	263	189	211	526	432	49	0	0	0	0	362	166	193	156	142	128	159	247	116	100	0	0	0	180	151	0	0	0	71	136	54
16	0	0	0	0	69	0	276	276	0	0	414	0	0	442	585	0	167	130	0	154	162	136	118	298	7	0	100	0	0	0	0	87	0	0	190	112	136	327	0	0	0	0	0	0	20
15	0	0	0	0	0	0	0	445	275	0	496	0	0	225	128	382	136	0	0	0	0	0	36	136	0	0	0	83	0	0	0	93	0	0	0	0	192	136	85	0	0	0	0	0	0
14	0	0	0	0	0	0	0	10	456	0	407	0	0	230	0	494	365	0	0	0	0	0	286	0	0	0	6	76	56	0	0	93	0	0	0	115	168	16	159	146	76	61	47	45	40
13	0	0	0	0	0	0	0	69	486	295	550	250	258	616	332	581	188	25	0	0	0	0	148	0	0	0	0	0	72	0	5	93	0	0	367	182	81	95	0	47	0	0	0	0	0
12	0	0	0	0	0	0	0	0	432	0	315	0	0	489	181	419	288	493	181	0	0	0	162	0	0	0	0	80	254	130	383	383	236	216	0	0	0	0	0	91	0	0	0	0	0
11	0	0	0	0	0	0	0	0	16	332	731	53	188	103	0	80	179	327	491	444	217	193	325	238	362	249	165	169	89	0	0	70	73	0	0	0	0	0	0	0	56	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	127	382	416	286	0	0	293	0	216	0	268	111	126	236	0	0	0	0	0	0	0	0	47	0	0	0	0	0	0	0	90	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	113	0	275	127	286	374	388	0	45	156	0	387	235	270	0	0	0	0	0	0	0	0	40	33	0	0	0	0	0	0	56	11	0	0	0
8	0	0	0	0	0	0	0	0	0	0	176	135	167	187	108	103	563	400	192	414	253	330	436	386	0	0	0	0	0	0	0	0	0	77	7	0	0	0	0	0	0	64	16	0	0
7	0	0	0	0	0	0	0	0	0	0	21	36	0	0	0	0	0	0	268	306	0	0	27	544	135	0	0	0	0	0	0	0	0	0	47	44	10	0	0	0	0	0	91	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	347	171	0	60	176	348	122	0	0	0	0	0	0	0	0	0	0	16	21	0	0	0	0	90	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	156	303	446	238	0	265	0	0	0	0	0	0	0	0	0	0	0	10	11	0	0	0	91	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	166	193	0	161	268	201	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	267	168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	214	156	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	700	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0

Figure A.8. Geographical Distribution of Freeway VMT in 2000, Thousands of Miles

SURFACE STREET VMT, 000

SURFACE STREET VMT, 000

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
26	0	11	0	0	89	71	211	26	12	0	9	5	6	11	15	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	1	6	1	0	6	0	0	6
25	20	80	99	195	252	274	217	117	46	99	43	0	0	21	11	5	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	19	2	0
24	56	190	116	191	264	205	270	227	166	10	97	192	0	19	0	0	4	0	0	0	0	0	4	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	37	26	15	17	0	3	0
23	41	290	267	300	290	335	240	133	195	75	9	49	144	70	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	30	0	2	1	53	26
22	129	202	229	281	74	236	411	326	341	347	175	22	180	44	250	148	19	11	0	0	0	3	4	0	0	0	0	0	0	0	0	0	0	0	4	1	2	27	1	30	1	0	42	95	0
21	110	26	33	40	93	207	201	195	220	77	111	406	205	51	444	341	250	250	171	111	26	40	41	33	47	0	0	7	20	0	2	12	16	15	90	35	20	36	47	144	72	14	17	0	0
20	3	6	0	0	0	23	52	181	167	176	236	373	164	223	312	177	207	270	166	91	71	204	180	130	81	61	76	78	137	71	46	12	20	5	90	69	60	78	236	160	87	54	20	3	0
19	61	53	0	0	0	42	144	326	717	795	391	195	144	122	337	900	311	277	143	147	179	189	170	44	27	131	157	91	132	95	60	30	46	53	170	95	101	66	175	186	17	26	33	0	5
18	0	20	28	32	109	335	679	764	907	633	838	1007	293	160	197	226	190	301	239	216	257	214	90	35	29	180	162	173	140	112	38	5	21	26	92	27	95	60	107	90	26	62	170	43	27
17	46	80	117	207	305	509	414	316	544	487	442	886	483	267	303	141	189	96	47	210	244	93	60	41	81	96	90	117	71	40	56	40	20	1	0	27	71	35	44	2	0	26	92	19	51
16	0	0	0	0	193	291	381	261	206	594	483	676	336	175	291	209	116	97	1	125	110	116	60	37	16	0	14	46	25	9	19	14	60	90	41	181	104	47	6	1	2	0	21	0	2
15	0	0	0	0	0	183	195	319	402	410	417	371	429	226	284	381	298	324	41	136	25	95	40	67	0	9	24	75	5	1	19	24	11	26	73	66	109	127	29	0	0	7	15	11	0
14	0	0	0	0	0	4	92	295	309	375	349	192	516	267	333	331	147	286	291	219	158	86	63	0	4	4	0	1	15	7	12	61	20	64	115	157	102	36	1	11	28	0	28	3	0
13	0	0	0	0	0	0	64	246	348	327	294	316	309	240	331	392	176	292	392	122	197	282	119	114	5	0	0	0	9	0	29	30	0	97	159	45	19	36	17	45	28	6	10	7	1
12	0	0	0	0	0	0	30	246	376	370	277	232	325	217	324	253	193	195	278	130	254	91	140	186	187	4	0	0	19	17	60	69	18	28	30	10	18	25	11	30	1	0	0	2	0
11	0	0	0	0	0	0	0	180	367	263	193	86	189	429	356	290	75	167	373	168	448	251	161	99	46	15	83	11	6	0	0	66	3	0	6	1	1	6	9	13	25	0	7	2	0
10	0	0	0	0	2	0	0	79	431	310	152	77	129	295	185	281	284	280	287	250	371	364	113	98	41	97	37	0	0	0	0	3	18	6	4	1	1	7	2	23	10	0	3	0	14
9	0	0	0	0	0	0	1	42	239	309	352	711	104	438	290	278	156	181	216	268	213	356	173	296	133	36	0	0	0	0	0	0	2	3	0	0	0	0	0	6	30	0	7	1	3
8	0	0	0	0	0	0	15	46	146	56	161	182	128	391	297	288	114	184	171	226	296	325	219	170	75	16	25	11	0	0	0	0	0	10	1	0	0	0	0	7	32	31	2	0	1
7	0	0	0	0	0	0	0	26	28	46	146	17	0	0	0	62	62	65	196	187	196	260	200	177	167	56	6	12	15	0	0	0	0	0	3	4	19	0	0	0	0	31	66	30	93
6	0	0	0	0	0	0	0	0	0	29	173	0	0	0	0	0	26	74	196	151	133	191	262	97	109	106	62	0	2	3	0	0	1	0	0	0	29	26	11	1	7	29	0	13	7
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	56	251	142	280	136	41	94	114	45	5	1	7	3	0	0	0	0	0	13	37	30	0	0	17	6	2	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	91	126	253	191	281	73	62	28	87	97	21	15	0	9	0	0	5	21	6	26	36	6	18	7	5	6
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	187	200	167	71	44	9	127	132	87	41	1	0	0	0	1	0	6	0	0	56	17	0	9	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	163	26	12	0	56	173	147	62	21	2	9	7	6	1	0	0	0	1	63	4	9	5	6
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	18	7	38	149	104	3	5	0	1	0	0	0	0	0	2	0	7	64	11	0	0

Figure A.9. Geographical Distribution of Surface Street VMT in 2000, Thousands of Miles

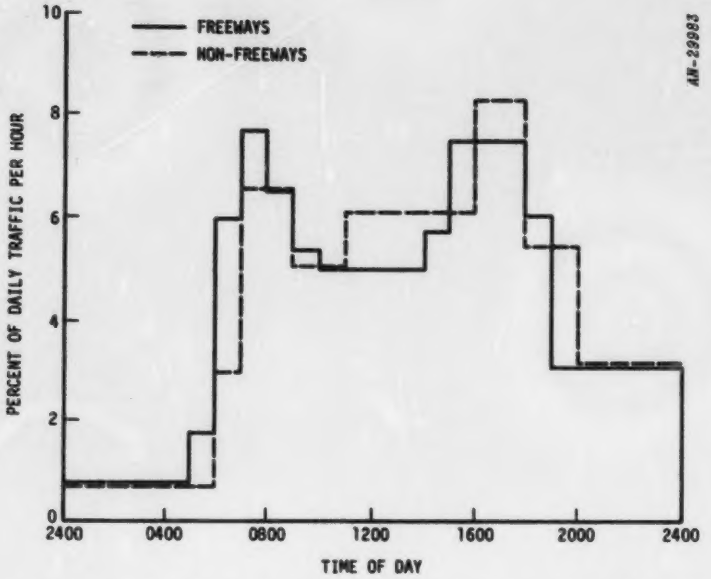

Figure A.10. Los Angeles Traffic/Time Distributions (Adapted from Roberts, Roth, and Nelson, Ref. 17)

as obtained for each hour from the SAI data for their grid in 1968. These average speeds were obtained as VMT-weighted averages for each hour between 6:00 and 10:00 a.m. Table A.2 shows the temporal distribution of average speeds and direction-volume ratios thus obtained, and subsequently used for all freeways in all years.

A.3 AVERAGE VEHICLE EMISSION FACTORS

The average gram-per-mile pollutant emissions from the vehicle population in a given year are weighted combinations of emissions from light-* and heavy-duty vehicles of various model years and ages, which are driven varying numbers of miles in their average use depending on age. Since 1963, the pollutant emissions from vehicles sold in California have been

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*For purposes of Federal and State emission control standards, vehicles weighing 6,000 pounds or less are defined as "light-duty;" those 6,001 pounds and over in gross weight are classified as "heavy-duty" vehicles.

TABLE A.1

DIURNAL VARIATIONS OF SOURCE ACTIVITIES (1974)

(Fraction of Daily Total Assignable to a 1-hour Period)

Local Time		Freeways	Surface Streets	Power Plants	Oil Refineries and Distributed Sources	
(Midnight)	2400-100	0.00776	0.00677	0.02756	0.01666	10%
	100-200	0.00776	0.00677	0.01911	0.01666	
	200-300	0.00776	0.00677	0.01695	0.01666	
	300-400	0.00776	0.00677	0.01484	0.01666	
	400-500	0.00776	0.00677	0.01381	0.01666	
	500-600	0.0178	0.00677	0.01484	0.01666	
A.M.	600-700	0.0591	0.0293	0.01695	0.06667	80%
	700-800	0.0768	0.0651	0.02334	0.06667	
	800-900	0.0648	0.0651	0.03709	0.06667	
	900-1000	0.0536	0.0502	0.04451	0.06667	
	1000-1100	0.0494	0.0502	0.05095	0.06667	
	1100-1200	0.0494	0.06088	0.05404	0.06667	
Noon	1200-1300	0.0494	0.06088	0.05616	0.06667	
	1300-1400	0.0494	0.06088	0.06043	0.06667	
	1400-1500	0.0569	0.06088	0.06146	0.06667	
	1500-1600	0.0746	0.06088	0.06387	0.06667	
	1600-1700	0.0746	0.0820	0.06043	0.06667	
	1700-1800	0.0746	0.0820	0.05940	0.06667	
P.M.	1800-1900	0.0598	0.0540	0.05724	0.01666	10%
	1900-2000	0.0302	0.0540	0.05306	0.01666	
	2000-2100	0.0302	0.03077	0.05404	0.01666	
	2100-2200	0.0302	0.03077	0.05616	0.01666	
	2200-2300	0.0302	0.03077	0.04771	0.01666	
(Midnight)	2300-2400	0.0302	0.03077	0.03606	0.01666	

TABLE A.2

AVERAGE FREEWAY FLOW SPEEDS AND DIRECTION-VOLUME RATIOS FOR SCAB GRID

Local Time	Average Speed in Slow Direction, mph	Average Speed in Fast Direction, mph	Traffic Volume Ratio Slow Direction / Fast Direction
0000-0500	60.0	60.0	1.00
0600	57.7	59.8	1.48
0700	44.3	59.3	1.32
0800	42.9	58.9	1.32
0900	52.6	59.7	1.18
1000-2400	60.0	60.0	1.00

subject to State, and subsequently, Federal limitations by model years. Compliance with standards is determined by emissions collected from the vehicle during operation over a prescribed speed-time schedule referred to as a driving cycle. It is these driving cycle emission factors which serve as the common basis permitting meaningful combinations of emissions over a range of vehicle model years. Current standards are based on the Federal Driving Cycle[25] (FDC) which was designed to simulate average vehicle operation during peak traffic hours within 7 miles of the central business district. The resulting simulated trip covers 7.47 miles at an average speed of 19.6 mph. Empirical speed correction techniques are used to predict emissions at average trip speeds other than this under both cruise and stop-and-go traffic conditions.[11,26]

Reference 11, compiled by GRC under the sponsorship of the California Department of Transportation, details the calculations required to arrive at vehicle emission factors for a prescribed mix of light- and heavy-duty California vehicles in a given calendar year. Basically, the method involves summing model-year FDC emission factors for all years prior to the target year, weighting them by (1) a deterioration factor which accounts for the loss in effectiveness of emission control systems with vehicle mileage, (2) the fraction of the daily VMT contributed by vehicles according to their ages and use, and (3) a speed correction factor for speeds other than the driving cycle average speed. In general, all of these factors will be functions of vehicle model year. As a practical matter, it is not necessary to consider all model years prior to the calendar year of interest, since after a certain age is reached, the mileage contributions become negligible.

The fraction of heavy-duty vehicles found in the urban mix is subject to considerable variation with locale. For the SCAB emissions model, we have assumed that on the average 5 percent of all VMT are contributed by heavy-duty vehicles. Reference 11 provides for the calculation of both cruise and stop-and-go emission factors over the range of speeds from 10 to 60 mph. Of course, in practice traffic does not flow smoothly at 10 mph nor can it maintain an average speed of 60 mph under stop-and-go conditions. The Highway Capacity Manual[27] indicates that the transition from stable traffic flow to unstable flow occurs rather abruptly at speeds immediately below 40 mph for multi-lane uninterrupted highways. Since we are only accounting for speed variations on freeways in our traffic model, we have assumed for the purposes of computing emission factors that all traffic at speeds of 40 mph and greater flows smoothly warranting use of cruise mode emissions. Freeway traffic averaging less than 40 mph would have emissions evaluated by the stop-and-go (sometimes called "average route speed") scaling method. It should be noted from Table A.2 that the assumption of geographically uniform speed distributions, made during the grid extension process, effectively put all freeway traffic in the cruise category. On the other hand, because the traffic model used does not include speed distributions for surface street traffic, emissions from surface street VMT are all assessed at a single speed under stop-and-go conditions. The speed chosen is 19.6 mph, the average speed of the FDC.

Figures A.11, A.12, and A.13 show the currently modeled speed variations of total HC, CO, and NO_x emission factors for the years 1970, 1980, 1990, and 2000 as obtained from Ref. 3. As noted in Ref. 11, 70.4 percent of vehicular HC emissions are treated as reactive based on earlier analyses of automobile exhaust. Unfortunately, data is lacking on the reactive fraction of exhaust emissions from vehicles equipped with advanced emission control systems such as catalytic converters. Should measurements of the reactive HC fraction from these devices prove to vary significantly from the assumed 70.4 percent, projections of future RHC contributions from vehicular sources would need to be reevaluated. Vehicular NO_x emissions are assumed to be 100 percent nitric oxide (NO). The vehicular emissions shown here are predicated on compliance with the current schedule of emission standards applicable to vehicles sold in California, and include the effects of the interim California Standards for 1975 set by EPA on April 11, 1973[28] and the one-year delay of the 1976 NO_x emission standard granted by EPA on July 30, 1973.[29] Table A.3 contains the resulting schedule

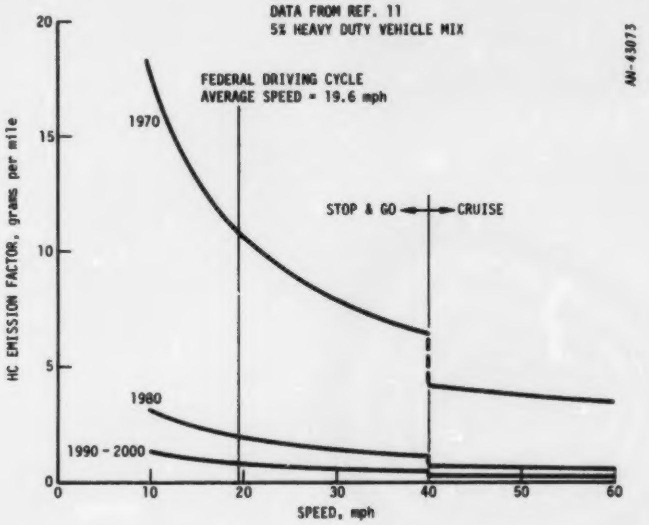

Figure A.11. Variation of Total HC Emissions with Traffic Speed

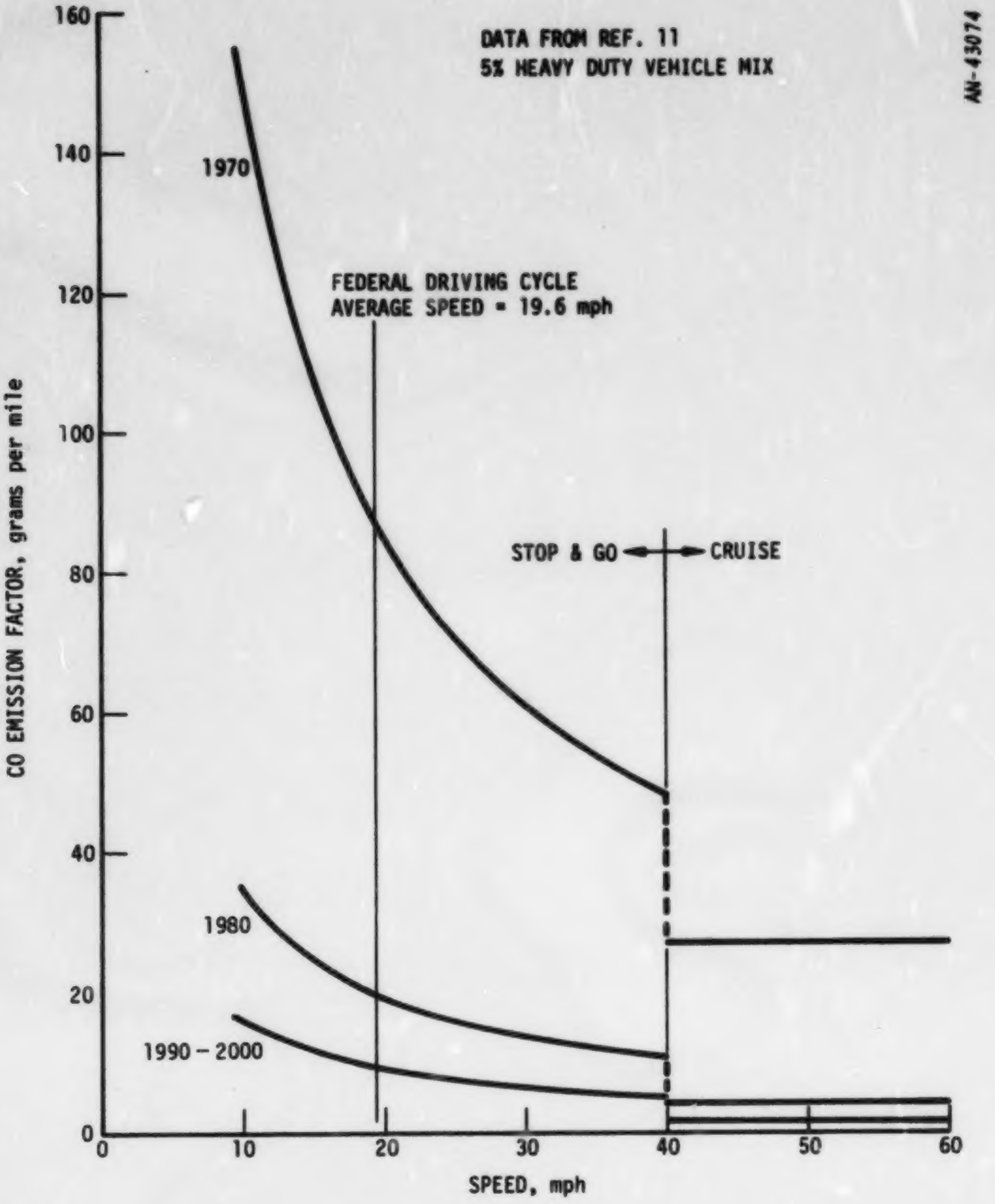

Figure A.12. Variation of CO Emissions with Traffic Speed

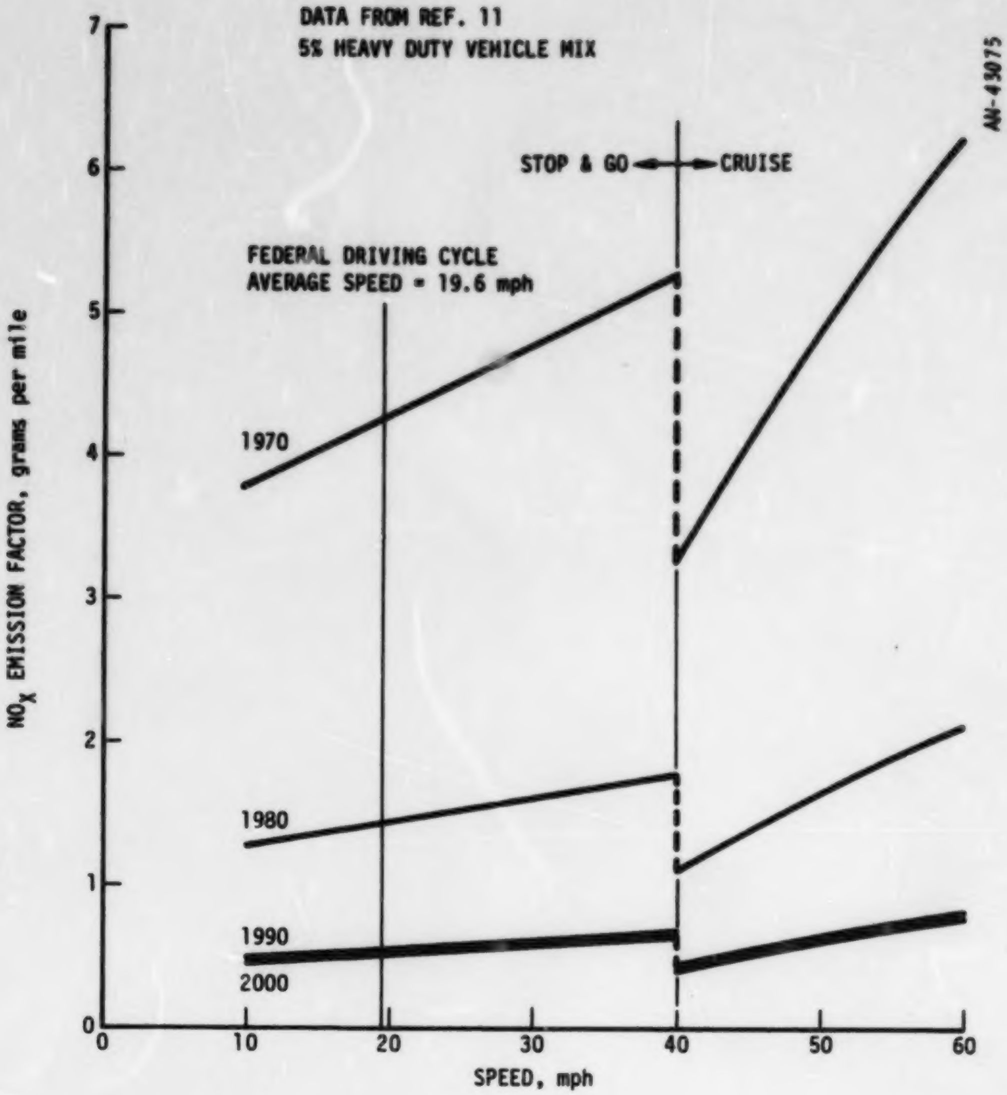

Figure A.13. Variation of NO_x Emissions with Traffic Speed

TABLE A.3

EXHAUST EMISSION STANDARDS FOR LIGHT-DUTY VEHICLES

		Emission Standards, grams per mile		
		HC	CO	NO_x
1972	Federal	3.4	39	3.0
	California	3.2*	39	3.2
1973	Federal	3.4	39	3.0
	California	3.2	39	3.0
1974	Federal	3.4	39	3.0
	California	3.2	39	2.0
1975	Federal	1.5	15	3.1
	California	0.9	9.0	2.0
1976	Federal	0.41	3.4	2.0
	California	1.0	9.0	2.0
1977	Federal	0.41	3.4	0.40
	California	1.0	9.0	2.0

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*Underlining denotes requirements for new California cars wherever differences arise between Federal and California standards.

of standards compiled in Ref. 11. (Emissions for vehicles prior to 1972 are based on measured data.)

Reference 15 gives the following light-duty vehicle emission factors for SO_2 and particulates independent of vehicle model year and traffic speed; 0.2 g/mi of SO_2, 0.38 g/mi of exhaust particulates, and 0.2 g/mi of particulates from tire wear. For heavy-duty vehicles, the emission factors are 0.26 g/mi of SO_2, 0.65 g/mi of exhaust particulates, and 0.2 g/mi of particulates from tire wear. These factors may be used in conjunction with estimates of regional VMT to calculate vehicular contributions to the daily SO_2 and particulate burden. Table A.4 shows the resulting estimated daily contributions for the study area assuming heavy-duty vehicles account for 5 percent of the VMT.

TABLE A.4

ESTIMATED DAILY VEHICULAR EMISSIONS OF SO_2 AND PARTICULATES IN STUDY AREA

Year	Daily VMT (× 10^6)	Emissions, Tons/Day	
		SO_2	Particulates
1970	134.3	20.2	82.2
1980	149.0	22.4	91.2
1990	162.0	24.4	99.2
2000	175.6	26.4	107.5

A.4 POWER PLANT EMISSIONS

In a companion report, Sjovold[13] has developed forecasts of electric power demand in the SCAB which are compatible with our fundamental assumptions regarding population growth.[6] Reference 13 supports three assumptions which are of importance to our estimation of future power plant emissions in the study area:

1. Except for those already under construction, no new power plants (nuclear or thermal) will be located in the SCAB. Any additional power generated in the region will be produced by uprating existing units, by retrofiting existing units with combined cycle* capability, and by construction of a few extra units at established thermal plants.
2. Natural gas is not expected to be available in any significant amount for power generation, as the available supply will probably be allocated to meet increasing residential demands. Hence, the thermal plants in the SCAB are expected to be almost entirely oil fired after 1980. (Currently,

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*Combined cycle refers to systems employing a combination of the Brayton and Rankine cycles, i.e., a direct combustion turbine (like a jet engine turbine) is employed both to drive a generator directly and to produce hot exhaust gases which are used to boost the output of the basic steam turbine unit.

increased residential demand for natural gas forces power plants and industry to use low-sulfur fuel oil during the winter months. Residential demand from April to November is generally low enough to permit power plants and industry to use natural gas.)

3. While the availability of low-sulfur oil ($\leq$0.5 percent by weight) may be a problem in the mid-1970s, the economic and technology of desulfurization indicate that low-sulfur oil or a non-petroleum equivalent should be in ready supply from 1980 on.

By the year 2000, nuclear stations sited outside the basin are expected to provide the major fraction of electrical generation capacity, meeting most of the continuous basic demand together with some hydroelectric sources. In the 1980s, fossil fueled plants (some coal fired plants outside the SCAB and the oil fired facilities within the region) will be providing some of the base load power and all of the peaking capacity. Figure A.14 shows a projection of the peak demand to be met by the generating facilities that really concern us here, the oil fired plants sited in the SCAB.* As the availability of nuclear power increases, less and less of the oil-fueled plant capacity will be used to satisfy the base load. Figure A.15 plots the resulting daily power cycle in the peak demand month (August) for the years 1974-1980, 1990, and 2000. These curves provide the time distribution functions needed for detailed forecasts of power plant emissions. Table A.1 contains data for the 1974-1980 time distribution converted into hourly fractions as needed to allocate total daily emissions. Similar tabulations for the projected 1990 and 2000 time functions are given in Table A.5.

The locations (in source grid coordinates), stack heights, and capacities of the 16 oil-fueled power plants in our study area are listed in

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*Four of these thermal plants (Mandalay, Cool Water, Ormond Beach, and Ellwood) lie outside our study area and hence, are not included in our current emissions model.

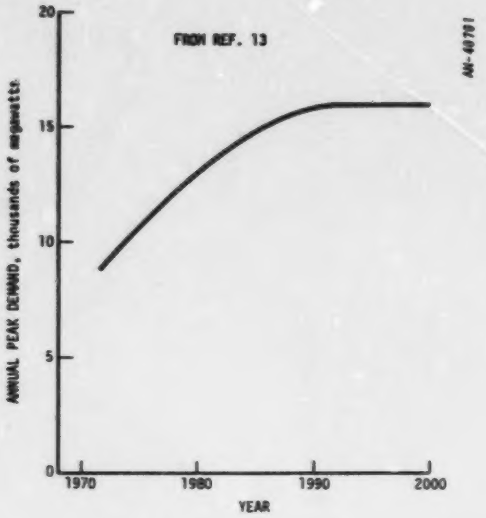

Figure A.14. Baseline Projected Peak Demand for Electricity Generated by Oil Fired Plants in the South Coast Air Basin

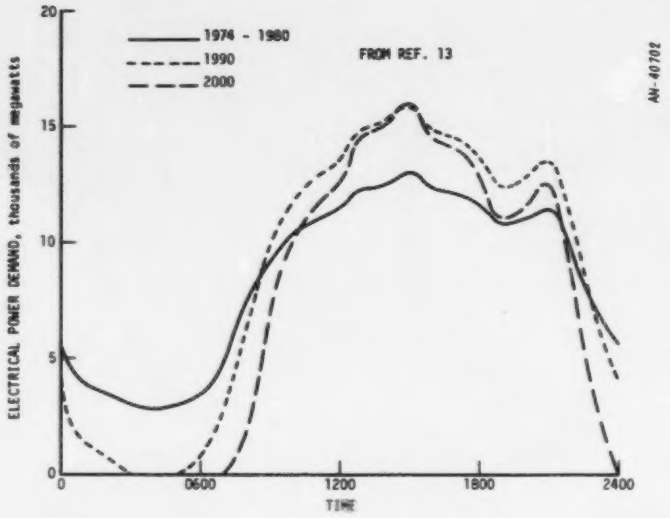

Figure A.15. Projected Baseline Diurnal Power Demand on Oil Fired Power Plants in the South Coast Air Basin

TABLE A.5

FUTURE POWER PLANT TIME FUNCTIONS FOR OIL FIRED UNITS IN THE SOUTH COAST AIR BASIN

(Fraction of Daily Total Assignable to a One-Hour Period)

Local Time	1990	2000
2400-0100	0.01984	0
0100-0200	0.00661	0
0200-0300	0.00331	0
0300-0400	0	0
0400-0500	0	0
0500-0600	0	0
0600-0700	0.00331	0
0700-0800	0.01322	0
0800-0900	0.02975	0.01133
0900-1000	0.04624	0.03966
1000-1100	0.05615	0.05666
1100-1200	0.06119	0.06516
1200-1300	0.06444	0.07082
1300-1400	0.07101	0.08215
1400-1500	0.07273	0.08499
1500-1600	0.07618	0.09065
1600-1700	0.07101	0.08215
1700-1800	0.06947	0.07932
1800-1900	0.06612	0.07365
1900-2000	0.05946	0.06232
2000-2100	0.06119	0.06516
2100-2200	0.06444	0.07082
2200-2300	0.05127	0.04816
2300-2400	0.03306	0.01700

Table A.6. Note that the capacities shown are for 1973, but three sites: Huntington Beach, Long Beach, and Scattergood are scheduled for capacity increases between 1973 and 1979. Based on data provided by Southern California Edison (SCE) and the Los Angeles Department of Water and Power (LADWP), Table A.7 shows the expected capacities of those plants, the total added power capacity, and the total study area capacity for each year through 1978 after which no additions are anticipated.

TABLE A.6

POWER PLANT DATA

		x, mi	y, mi	I	J	Average Stack Height, ft	1973 Capacity, MW
1.	Los Alamitos	31.8	14.9	16	8	214	2071
2.	El Segundo	13.2	24.7	7	13	222	1020
3.	Redondo Beach	15.0	20.5	8	11	214	1602
4.	Huntington Beach	38.8	6.4	20	4	211	880*
5.	Long Beach	25.0	13.9	13	7	220	212*
6.	Harbor	22.4	15.0	12	8	250	525
7.	Haynes	32.1	14.4	17	8	240	1593
8.	Scattergood	11.9	28.3	6	15	310	358*
9.	Valley	15.1	47.7	8	24	510	517
10.	Pasadena	29.1	39.5	15	20	60	230
11.	Burbank	19.6	43.1	10	22	60	174
12.	Glendale	21.7	41.5	11	21	88	153
13.	Etiwanda	66.7	36.9	34	19	188	1025
14.	Highgrove	77.9	32.5	39	17	85	154
15.	San Bernardino	83.0	36.3	42	19	130	126
16.	Garden State	54.7	33.8	28	17	50	12

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*See Table A.7 for schedule of increased capacity.

TABLE A.7

POWER PLANT CAPACITY SCHEDULE

Number	Plant	Capacity, MW					
		1973	1974	1975	1976	1977	1978
4	Huntington Beach	880	880	1,252	1,624	1,960	2,296
5	Long Beach	212	212	465	465	465	465
8	Scattergood	358	667	667	667	667	667
	"New" Power	0	309	934	1,306	1,642	1,978
	Study Area Total	10,652	10,961	11,586	11,958	12,294	12,630

On the assumption that the emissions characteristics of the power plants in the L.A. area are reasonably uniform, and that power demand is allocated to plants in proportion to their capacities, our model distributes power plant emissions in the same way. Table A.8 summarizes the total daily emissions of NO_x, SO_2, and particulates reported by the air pollution control districts of Los Angeles,[12] Orange,[30] and San Bernardino[31] Counties for 1971 for the power plants in the study area. (Hydrocarbon emissions from power plants contribute less than 0.2 percent of the total HC burden and hence are considered negligible.)

TABLE A.8

1971 EMISSIONS FROM POWER PLANTS IN THE STUDY AREA

County	Emissions, Tons/Day		
	NO_x	SO_2	Particulates
Los Angeles	100	160	5
Orange	11	0	0
San Bernardino	9.4	14.6	2.5
Totals	120.4	174.6	7.5

The emissions reported by the LACAPCD were generated on 28 percent natural gas and 72 percent low-fulfur oil averaging 0.45 percent sulfur by weight. We have assumed that the remainder of the plants used 100 percent low-sulfur oil at 0.5 percent sulfur content, the legal limit. Thus the assumed shift to 100 percent low-sulfur oil for all SCAB power plants by 1980 will result in increased emissions of SO_2 and particulates from existing facilities. EPA[15] emission factors indicate that the effect on NO_x emissions should be negligible. To provide a basis for scaling SO_2 and particulate emissions, we computed equivalent 1971 emissions as if only 0.5 percent low-sulfur oil had been used. Again using the EPA[15] emission factors as a guide we note that SO_2 emissions using natural gas are negligible compared to those from oil-fired boilers. However, particulate emissions using gas are 26.8 percent of their oil-produced counterpart. The hypothetical SO_2 emissions are computed as follows (see Table A.8):

For Los Angeles County

$$\frac{160\text{ tons/day}}{0.72}\left(\frac{0.0050}{0.0045}\right) = 246.9\text{ tons/day of }SO_2$$

and adding the contribution from San Bernardino County (which we assumed to be using 0.5 percent low-sulfur oil already) we obtain the equivalent total emissions of

$$246.9 + 14.6 = 261.5\text{ tons/day of }SO_2$$

To calculate the corresponding particulate emissions, we first determine that of the 5 tons per day contributed by Los Angeles County, 4.53 tons came from the burning of fuel oil and 0.47 tons from burning natural gas. Then we proceed as outlined above for SO_2, except that the difference in sulfur content of the oil does not affect particulate emissions. Hence,

$$\frac{4.53\text{ tons/day}}{0.72} + 2.5 = 8.79\text{ tons/day of particulates}$$

Emissions from new power generating facilities coming on line in the L.A. region are limited by Rule 67 to 140 lb/hr of NO_x, 200 lb/hr of SO_2, and 10 lb/hr of particulates.[32] The added power generating capacity shown in Table A.7 amounts to a total of 1,978 MW from 17 separate additions. If we assume that Rule 67 applies "per addition" operated at its capacity, then we can calculate emission factors per megawatt-hour delivered by the new facilities. Table A.9 compares the resulting power generation emission factors for existing capacity in 1971 (meeting an average demand of 5,590 MW) and for new and existing facilities using low-sulfur oil exclusively.

Finally, using the schedules of existing and planned capacity in the study area (Tables A.6 and A.7), the projected demand on that generating capacity (see Figs. A.14 and A.15), and the power generation emission factors in Table A.9, we can project total power plant emissions of NO_x, SO_2, and particulates for future years. Assuming that power demand is distributed such that all units operate at the same fraction of their total capacities, Table A.10 lists the expected schedule of pollutant emissions.

TABLE A.9

POWER GENERATION EMISSION FACTORS

	1971 Emissions, Tons/Day	Existing Power Emission Factor, kg/MW·hr	Maximum Emissions from Added Power, Tons/Day	"New" Power Emission Factor, kg/MW·hr
NO_x	120.4	0.814	28.6	0.547
SO_2	174.6	1.183	40.8	0.780
	262 (oil)	1.1772		
Particulates	7.5	0.0507	2.04	0.0390
	8.79 (oil)	0.0594		

TABLE A.10

PROJECTED POLLUTANT EMISSIONS FROM POWER PLANTS IN THE STUDY AREA

Year	Total Capacity, MW	Average Demand, MW	Emissions, Tons/Day		
			NO_x[*]	SO_2	Particulates
1971	10,652	5,590	120.4	175	7.5
1980	12,630	8,480	173.6	362	12.6
1990	12,630	8,700	178.1	372	12.9
2000	12,630	7,350	150.5	315	10.9

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[*] To convert to nitric oxide, multiply by the factor 30/46.

Geographic distribution of the NO_x emissions in Table A.10 in proportion to power plant capacity provides average daily NO_x emissions at each site as required by the GRC and SAI smog models. Table A.11 displays these data.

A.5 PETROLEUM REFINERY EMISSIONS

On a SCAB regional basis, emissions from petroleum refineries are relatively small, but since refineries are concentrated sources, their emissions can be important on the local scale. The SAI data base[24] previously used in the DIFKIN code simply prorates total petroleum refinery emissions of NO_x and reactive HC as reported by the Los Angeles County APCD to individual refinery locations according to their crude oil capacities. Since no additional refineries are in the expanded study area, we have retained the SAI refinery data, transferring locations onto the new grid, adding estimates of current and future total emissions of SO_2 and particulates from petroleum refinery operations, and updating the inventory emissions of NO_x and HC relative to the original SAI model.[24]

TABLE A.11

GEOGRAPHIC DISTRIBUTION OF NO_x EMISSIONS FROM POWER PLANTS

	I	J	Emissions, kg/hr			
			1971	1980	1990	2000
1. Los Alamitos	16	8	885	1076	1104	933
2. El Segundo	7	13	436	530	544	459
3. Redondo Beach	8	11	684	833	854	722
4. Huntington Beach	20	4	376	1193	1224	1034
5. Long Beach	13	7	91	242	248	209
6. Harbor	12	8	224	273	280	236
7. Haynes	17	8	681	828	849	718
8. Scattergood	6	15	153	347	356	300
9. Valley	8	24	221	296	276	233
10. Pasadena	15	20	98	120	123	104
11. Burbank	10	22	74	90	93	78
12. Glendale	11	21	65	80	82	69
13. Etiwanda	34	19	438	533	546	462
14. Highgrove	39	17	66	80	82	69
15. San Bernardino	42	19	54	65	67	57
16. Garden State	28	17	5	6	6	5

The pollutant emissions from petroleum refineries listed by the LACAPCD[12] for 1970 are 68.4 tons per day of NO_x, 61.6 tons per day of total hydrocarbons, 55.4 tons per day of SO_2, and 10.1 tons per day of particulates. As recommended by SAI in Ref. 14 we have retained 50 percent (30.8 tons per day) of the total HC emissions from petroleum refineries as reactive enough to participate in the formation of photochemical smog.*

---

*The recommended reactivity definition includes as reactive all hydrocarbons except methane, ethane, propane, benzene, and acetylene.

Current uncertainties as to future oil supplies in the US make it difficult to forecast petroleum refinery activities with confidence, but we have taken the view that any real energy shortage which can be eased by the expansion of refining capacity will probably lead to relaxations of environmental restraints opposing that expansion. Therefore, reasoning that it is national demand which will be the prime consideration in determining gasoline and fuel oil production, we have scaled oil refinery emissions in the SCAB with the projected national population to arrive at an emissions forecast for 1980, 1990, and 2000.

In keeping with our assumptions concerning population growth in the study area,[6] we extrapolated the national population using Bureau of the Census Series E projections.[33] Table A.12 gives the schedule of pollutant emissions from petroleum refineries in the study area.

Table A.13 reprints the petroleum refinery data contained in Table A.23 of Ref. 24, translating the refinery locations into the new grid coordinate system. The geographical emissions distributions for NO_x and reactive HC given in Table A.14 were obtained by allocating the total daily

TABLE A.12

POLLUTANT EMISSIONS FROM PETROLEUM REFINERIES IN THE STUDY AREA

Year	US Population[33] ($x10^6$)	Growth Factor	Emissions, tons/day			
			NO_x*	Reactive HC	SO_2	Particulates
1970	204.88	1.0	68.4	30.8	55.4	10.1
1980	224.13	1.094	74.8	33.7	60.6	11.0
1990	246.64	1.204	82.4	37.1	66.7	12.2
2000	264.44	1.291	88.3	39.8	71.5	13.0

---

*Multiply by 30/46 to convert to nitric oxide.

TABLE A.13
PETROLEUM REFINERY DATA[24]

		x, mi	y, mi	I	J	Crude Capacity (10^3 Barrels/Stream Day)
1.	Atlantic Richfield Company	24.2	17.3	13	9	173
2.	Douglas Oil Company of California	29.2	23.9	15	12	26
3.	Edington Oil Refineries, Inc.	28.3	21.9	15	11	16
4.	Fletcher Oil and Refining Company	21.6	18.2	11	10	13
5.	Carson Oil Company, Inc.	21.3	19.8	11	10	10
6.	Gulf Oil Corp.	34.7	24.7	18	13	51
7.	Lunday-Thagard Oil Company	28.1	27.5	15	14	3
8.	MacMillan Ring-Free Oil Company	28.0	16.4	15	9	10
9.	Mobil Oil Corp.	18.1	20.7	10	11	130
10.	Powerine Oil Company	33.9	26.3	17	14	30
11.	Shell Oil Company	23.9	20.0	12	11	44
12.	Shell Oil Company	23.6	17.8	12	9	44
13.	Standard Oil of California	14.0	24.6	8	13	210
14.	Texaco, Inc.	24.1	16.3	13	9	61
15.	Union Oil Company of California	23.7	15.6	12	8	107

emissions in Table A.12 to each refinery in proportion to its crude capacity as listed in Table A.13 and combining emissions where two refineries are located in the same grid square. These emissions are temporally distributed as shown in Table A.1

A.6 AREA SOURCE EMISSIONS

The distributed source category includes industrial, commercial, and residential activities such as fuel combustion (for temporary power generation, power-driven machinery and space heating), petroleum marketing (e.g., gasoline distributors and service stations), and the use of

TABLE A.14

GEOGRAPHIC DISTRIBUTION OF NO_x AND REACTIVE HC EMISSIONS FROM PETROLEUM REFINERIES

	Location		Emissions, kg/hr							
			1970		1980		1990		2000	
I.D. Number	I	J	NO_x	RHC	NO_x	RHC	NO_x	RHC	NO_x	RHC
1. and 14.	13	9	652	294	713	322	785	354	842	380
2.	15	12	72	33	79	36	87	40	93	43
3.	15	11	45	20	49	22	54	24	58	26
4. and 5.	11	10	64	29	70	32	77	35	83	37
6.	18	13	142	64	155	70	171	77	183	83
7.	15	14	8	4	9	4	10	5	10	5
8.	15	9	28	13	31	14	34	16	36	17
9.	10	11	362	163	396	178	436	196	467	210
10.	17	14	84	38	92	42	101	46	108	49
11.	12	11	123	55	135	60	148	66	159	71
12.	12	9	123	55	135	60	148	66	159	71
13.	8	13	585	263	640	288	704	317	755	340
15.	12	8	298	134	326	147	359	161	385	173

organic solvents (for dry cleaning, degreasing, and surface coating). Data for area source emissions were obtained from the source inventories compiled by the air pollution control districts of Los Angeles,[12] Orange[30] and San Bernardino[31] Counties. At the time this emissions model was being assembled, we were unable to obtain an emissions inventory for Riverside County. Area source emissions in that portion of the study area were synthesized by a technique using land-use emission factors, to be described presently.

Average daily SO_2 and particulate emissions from distributed sources in the study area are aggregated in Table A.15. (Aircraft emissions are

TABLE A.15

DISTRIBUTED SOURCE EMISSIONS OF SO_2 AND PARTICULATES, 1971

a. SO_2 Emissions, Tons/Day

County	Los Angeles	Orange	San Bernardino	Riverside*	Total
Chemical Industry	117				117
Metallurgical Industry	2.8		26.2	9.9	38.9
Mineral Industry		2.0			2.0
Other Industry		4.6			4.6
Petroleum Production		4.0			4.0
Commercial		0.1	4.1	1.1	5.3
Residential		0.1			0.1
Aircraft and Railroad	4	1.2	0.9		6.1
Total	123.8	12.0	31.2	11.0	178.0

b. Particulate Emissions, Tons/Day

County	Los Angeles	Orange	San Bernardino	Riverside*	Total
Chemical Industry	11	0.2			11.2
Metallurgical Industry	11	0.4	4.5	1.7	17.6
Mineral Industry	6	2.3	6.9	2.6	17.8
Other Industry	6.4	1.2			7.6
Petroleum Production					0.0
Commercial	8.1	0.4	1.6	0.4	10.5
Residential	5	0.4			5.4
Aircraft and Railroad	13	4.3	0.9		18.2
Total	60.5	9.2	13.9	4.7	88.3

---

*Riverside County emissions estimated from San Bernardino County emissions based on the ratio of land areas devoted to industrial or commercial use (see Table A.21).

only included here as a convenience in calculating total regional emissions of SO_2 and particulates.) Daily area source emissions of NO_x and total hydrocarbons (THC) abstracted from the district inventories[12,30,31] are listed in Tables A.16, A.17, and A.18. The reactive hydrocarbon (RHC) emissions shown in these tables are based on a reassessment by SAI[14] of the participation of individual hydrocarbons in the smog formation process.

TABLE A.16

HC AND NO_x EMISSIONS FROM DISTRIBUTED SOURCES IN LOS ANGELES COUNTY, 1971

(From Ref. 12)

	Emissions, Tons/Day		
	THC	RHC	NO_x
Chemical Industry	107	0	10
Metallurgical Industry	2.3	1.7	13.6
Mineral Industry	1	1.0	8
Petroleum Marketing			
Underground Tanks (Service Stations)	30.3	30.3	
Automobile Tanks (Service Stations)	56.8	56.8	
Surface Coating (Protective, Architectural)	20	15	
Other (Distribution Transfers)	22.7	22.7	10.5
Other Industries			
Surface Coating	110	82.5	
Degreasing	95	71.3	
Other Solvent Use	35	26.2	
Miscellaneous	0.4	0.3	2.4
Commercial Activity	55.1	41.3	23.1
Residential	67	50.3	24
Total	602.6	399.4	91.6

TABLE A.17

HC AND NO_x EMISSIONS FROM DISTRIBUTED SOURCES IN ORANGE COUNTY, 1971

(From Ref. 30)

	Emissions, Tons/Day		
	THC	RHC	NO_x
Chemical Industry			0.3
Mineral Industry			0.7
Petroleum Marketing	18	18	
Other Industries			5.5
Organic Solvents Use	31.5	23.6	
Incineration	0.2	0.2	0.2
Domestic and Commercial			5.2
Ships and Railroads	0.1	0.1	0.2
Total	49.8	41.9	12.1

TABLE A.18

HC AND NO_x EMISSIONS FROM DISTRIBUTED SOURCES IN SAN BERNARDINO COUNTY, 1971

(From Ref. 31)

	Emissions, Tons/Day		
	THC	RHC	NO_x
Petroleum Marketing	10	10	
Organic Solvents Use	8.2	6.2	
Industrial and Commercial	0.7	0.4	12.4
Aircraft and Railroads	0.7	0.7	0.8
Total	19.6	17.3	13.2

We concur with the SAI recommendations that, in the long run, all hydrocarbons except methane, ethane, propane, benzene and acetylene should be considered "reactive." Using this definition, SAI estimated that HC emissions from petroleum marketing operations are 100 percent reactive, and that HC emissions from the various solvent uses (degreasing, surface coating, dry cleaning, etc.) are 75 percent reactive.

Prediction of future distributed source emissions in the study area requires that we account for two competing effects on the sources involved, (1) the growth of emissions with increased population and the associated expansion of industry, commerce, and housing, and (2) the opposing effects of the California State Implementation Plan (SIP)[17] for the South Coast Air Basin which seeks to reduce pollutant emissions and bring the area more nearly into compliance with the national ambient air quality standards. Prior to promulgation of the SIP, the California State Air Resources Board (ARB) published estimates of future NO_x and HC emissions in the SCAB in its 1970 annual report.[34] These estimates showed no measurable growth in stationary source emissions of HC. NO_x emissions from distributed sources were seen to follow the growth shown in Fig. A.16. We have assumed that total area source emissions of SO_2 and particulates scale with local (SCAB) population. The emissions controls on stationary sources specified in the SIP will have a major impact on future emissions of HC, but negligible effect on other pollutants. Stationary source controls will take the form of requirements for vapor recovery devices to greatly reduce evaporative emissions from gasoline transfer operations, substitution of less reactive organic solvents for those currently used in degreasing and dry cleaning operations, and institution of additional control measures affecting surface coating and dry cleaning operations. We have assumed that the controls proposed in the SIP will be accepted by EPA and will have reached full application by 1980. These stationary source controls are expected to effect the reductions in reactive HC emissions shown in Table A.19.*

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*Based on emissions reduction estimates in a working paper by N.A. Moyer of the California State Air Resources Board, December 1973.

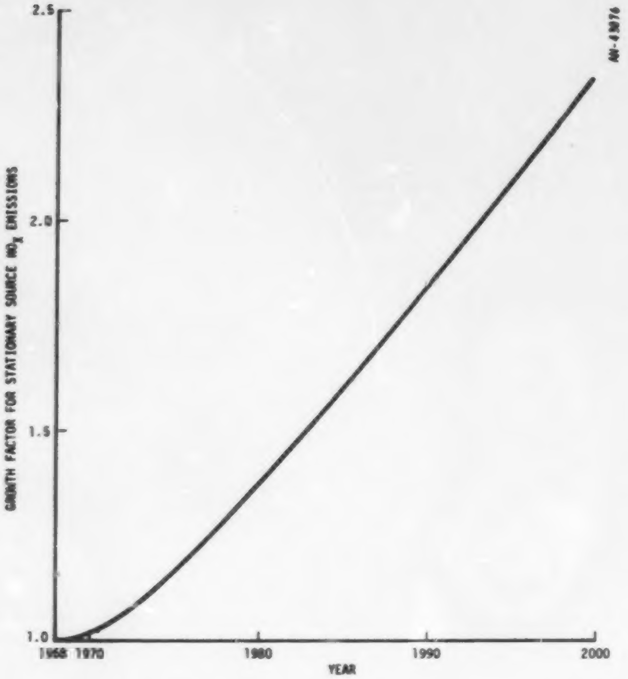

Figure A.16. Growth of Distributed Source NO_x Emissions

TABLE A.19

REACTIVE HC EMISSIONS REDUCTIONS UNDER THE SIP

Source Type	Expected Reductions 1975	1977	1980 (Full Application)
Petroleum Marketing	30%	55%	90%
Degreasing	80%	90%	100%
Surface Coating	20%	30%	35%
Dry Cleaning	95%	95%	95%
Miscellaneous	∿40%	∿50%	∿55%

To determine the overall effect of these reductions on RHC emissions from stationary sources, we have evaluated the hypothetical application of the final SIP reductions in Table A.19 to the relevant portions of the study area emissions inventory for 1971. These calculations, outlined in Table A.20, show that at full application the SIP should reduce RHC emissions from distributed stationary sources to approximately 34 percent of their anticipated, uncontrolled levels. Hence, this factor was applied in all projections of stationary source inventories for 1980 and later. Estimates of the corresponding factors for intermediate years (1975-1980) may be made by recalculating the righthand portion of Table A.20 using the appropriate percentage reductions from Table A.19.

It was originally our intention to use maps of existing land-use in the study area as a basis for geographical distribution of current stationary source emissions. Unfortunately, the only regional land use map available was a future land-use plan published by the Southern California Association of Governments (SCAG) called the SCAG 90 Land Use Plan for the Southern California Metropolitan Area. This map shows major areas or concentrations of six types of land-use in a region essentially coterminous with the LARTS Study Area shown in Fig. A.2, covering approximately 11,300 square miles of land area. The land use categories employed by SCAG are

0	Agriculture, Open Space and Vacant Land
1	Low Density Urban (1000 to 8000 persons per square mile)
2	Medium Density Urban (8000 to 20,000 persons per square mile)
3	Major Public Facilities and Military
4	Urban Center
5	Industrial

where the order and type indices are ours, added for ease of identification. To organize the geographical distribution of these areas in terms of our source grid of 2-by-2-mile squares, we overlaid the grid on the land-use map and employed a coded number to identify the fraction of each

TABLE A.20

HYPOTHETICAL REDUCTIONS IN REACTIVE HYDROCARBON EMISSIONS FOR 1971 UNDER FULL APPLICATION OF THE SIP

Source Type	Emissions, tons/day						
	Estimated Pre-SIP Emissions by County (See Note)				Study Area Total	Estimated SIP Reduction	Post SIP Emissions
	Los Angeles[12]	Orange[30]	San Bernardino[31]	Riverside*			
Petroleum Marketing	109.8	18	10	5	142.8	128.5	14.3
Degreasing	71.3	1.5			72.8	72.8	0
Surface Coating	172	7.5			179.5	62.8	116.7
Dry Cleaning	18.8	1.9			20.7	19.7	1.0
Other	26.5	12.8	6.6	3.3	49.2	27.1	22.1
Stationary Sources Unaffected by SIP Controls	1.0	0.2	0.7	0.3	2.2	---	2.2
Total	399.4	41.9	17.3	8.6	467.2	310.9	156.3

NOTE: The category totals shown here include contributions from some of the broader source categories listed in Tables A.16, A.17, and A.18 (e.g., Commercial and Residential) as itemized in the respective references.

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*Total emissions for Riverside County portion of study area were estimated using land-use emission factors calculated for San Bernardino County. The various source categories were assumed to contribute in the same proportions as in San Bernardino (see Tables A.22 and A.23).

square devoted to each land-use within ±5 percent. Thus a typical square might be 0.6 type 1, 0.1 type 2, and 0.3 type 5.

The emissions sources listed in Tables A.16, A.17, and A.18 can reasonably be divided into industrial, commercial, and residential categories. However, there is no simple one-to-one correspondence between these categories and the land-use types listed above. Only the allocation of industrial emissions is relatively straightforward. We observe that the coarseness of both our fractional allocation scheme and of the map itself preclude individual representation of "islands" of commercial land use less than about 0.2 square miles (~13 acres), yet there are obviously many such neighborhood commercial establishments within most low- and medium-density urban areas. Probably the most important case in point is the corner gasoline service station. The only land-use category on the SCAG map which is clearly commercial in nature is the urban center, which is often found attached to an area of type 2, medium-density urban land-use. We also noted that no inventory emissions are readily identified as type 3. Most type 3 areas are associated with public and military airports and hence might properly be used to distribute aircraft emissions. However, in terms of the stationary source emissions being considered here, military facilities on sizeable pieces of land more nearly resemble residential or commercial/residential civilian areas. Having made these preliminary observations, the following ad hoc assumptions were made concerning allocation of inventory emissions to land use types:

1. No emissions are allocated to type 0 areas.
2. Type 4 areas are combined with type 2 areas into an "urban-commercial" category.
3. Type 3 areas receive the same final allocation as type 1 areas.
4. "Residential" source emissions are spread over areas of type 1 through 4 with types 2 and 4 (urban-commercial) receiving double weighting compared to 1 and 3.

5. "Commercial" source emissions are allocated 50% to the urban-commercial areas and 50% to the type 1 and 3 areas.
6. "Industrial" source emissions are only allocated to type 5 areas.

Table A.21 shows the total land areas in each land-use category and county within the study area.

In identifying the emissions in the inventories of Tables A.16, A.17, and A.18 as residential, commercial or industrial, the following assumptions were made:

1. Los Angeles--All petroleum marketing emissions with the exception of those associated with distribution transfers were put in the residential category.
2. Orange--Reactive HC emissions, dominated by petroleum marketing and organic solvents use, were split roughly half-and-half between the residential and industrial categories.

TABLE A.21

LAND USE AREAS IN THE STUDY REGION

(Units Are 2-by-2-mile Squares)

County	Low Density Urban (1)	Urban-Commercial (2 and 4)	Public, Military Facilities (3)	Industrial (5)	Total Populated Area
Los Angeles	190.8	28.5	2.2	41.1	262.6
Orange	84.8	4.6	4.1	11.3	104.8
San Bernardino	45.3	1.1	3.0	9.3	58.7
Riverside	27.6	0.3	4.0	3.5	35.4
Study Area	348.5	34.5	13.3	65.2	461.5

3. San Bernardino--Reactive HC emissions from petroleum marketing and organic solvents use were split roughly half-and-half between the residential and industrial categories. Industrial and commercial RHC was split 50:50. Industrial and commercial NO_x was allocated to give emissions per unit area similar to Los Angeles County in the industrial and urban-commercial areas.

Table A.22 shows the resulting allocation of these inventories by source type.

The ad hoc rules listed above for allocation of the residential, commercial, and industrial emissions in Table A.22 to the land-use areas in Table A.21 are implemented by the following equations:

$$Q_1 = C\left[\frac{T_1}{A_1 + 2(A_2 + A_4) + A_3} + \frac{T_2}{2(A_1 + A_3)}\right] \quad (A.1)$$

$$Q_2 = C\left[\frac{2T_1}{A_1 + 2(A_2 + A_4) + A_3} + \frac{T_2}{2(A_2 + A_4)}\right] \quad (A.2)$$

TABLE A.22

STUDY AREA EMISSIONS OF NO_x AND REACTIVE HC FROM STATIONARY SOURCES

	Emissions, Tons/Day							
	Residential		Commercial		Industrial		Total	
County	NO_x	RHC	NO_x	RHC	NO_x	RHC	NO_x	RHC
Los Angeles	24.0	152.4	23.1	41.3	44.5	205.7	91.6	399.4
Orange	5.2	20.0	---	---	6.9	21.9	12.1	41.9
San Bernardino	3.4	8.0	1.0	0.2	8.8	9.1	13.2	17.3
Riverside*	2.37	5.1	0.27	0.1	3.3	3.4	5.94	8.6

---

*Calculated from land-use emission factors for San Bernardino. See Table A.23.

$$Q_3 = Q_1 \qquad \text{(A.3)}$$

$$Q_4 = Q_2 \qquad \text{(A.4)}$$

$$Q_5 = C\,\frac{T_5}{A_5} \qquad \text{(A.5)}$$

where A_i = Area devoted to land-use type i (see Table A.21)

C = Conversion factor from tons/day to kg/hr

T_j = Pollutant emissions from type j sources, tons/day (see Table A.22)

with $j = 1$ = residential

$j = 2$ = commercial

$j = 5$ = industrial

Q_i = Land-use emission factor for type i areas, kg/hr/unit area

Application of these equations for each pollutant and county yields the land-use emission factors for 1971 given in Table A.23.

Assuming that land-use emissions in Riverside County should be similar to those in San Bernardino County, we were able to reconstruct an estimated emissions inventory for Riverside County (see Table A.22) by solving Eqs. A.1 through A.5 for T_1 through T_5 using the Q's for San Bernardino and the A's for Riverside.

Finally, the land-use emission factors in Table A.23 were used with the land use breakdown in each grid square to assemble a single average daily emission factor for NO_x and RHC in each square. Figures A.17 and A.18 show the resulting geographical distributions of NO_x and reactive HC emissions from stationary sources in the study area for 1971. These

TABLE A.23

LAND-USE EMISSION FACTORS IN THE STUDY AREA, 1971

(Units are kg/hr per 2-by-2-mile Square)

Pollutant	County	Low Density Urban (1)	Urban-Commercial (2 and 4)	Public, Military Facilities (3)	Industrial (5)
NO_x	Los Angeles	5.9	22.6	5.9	40.9
	Orange	2.0	4.0	2.0	23.1
	San Bernardino	2.9	22.3	2.9	35.8
	Riverside*	2.9	22.3	2.9	35.8
Reactive HC	Los Angeles	27.1	73.5	27.1	189.2
	Orange	7.7	15.4	7.7	73.3
	San Bernardino	6.1	15.4	6.1	37.0
	Riverside*	6.1	15.4	6.1	37.0

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*Lacking an emissions inventory for Riverside, we have assumed that the land-use emission factors for San Bernardino County (SCAB portion) are also applicable in Riverside County.

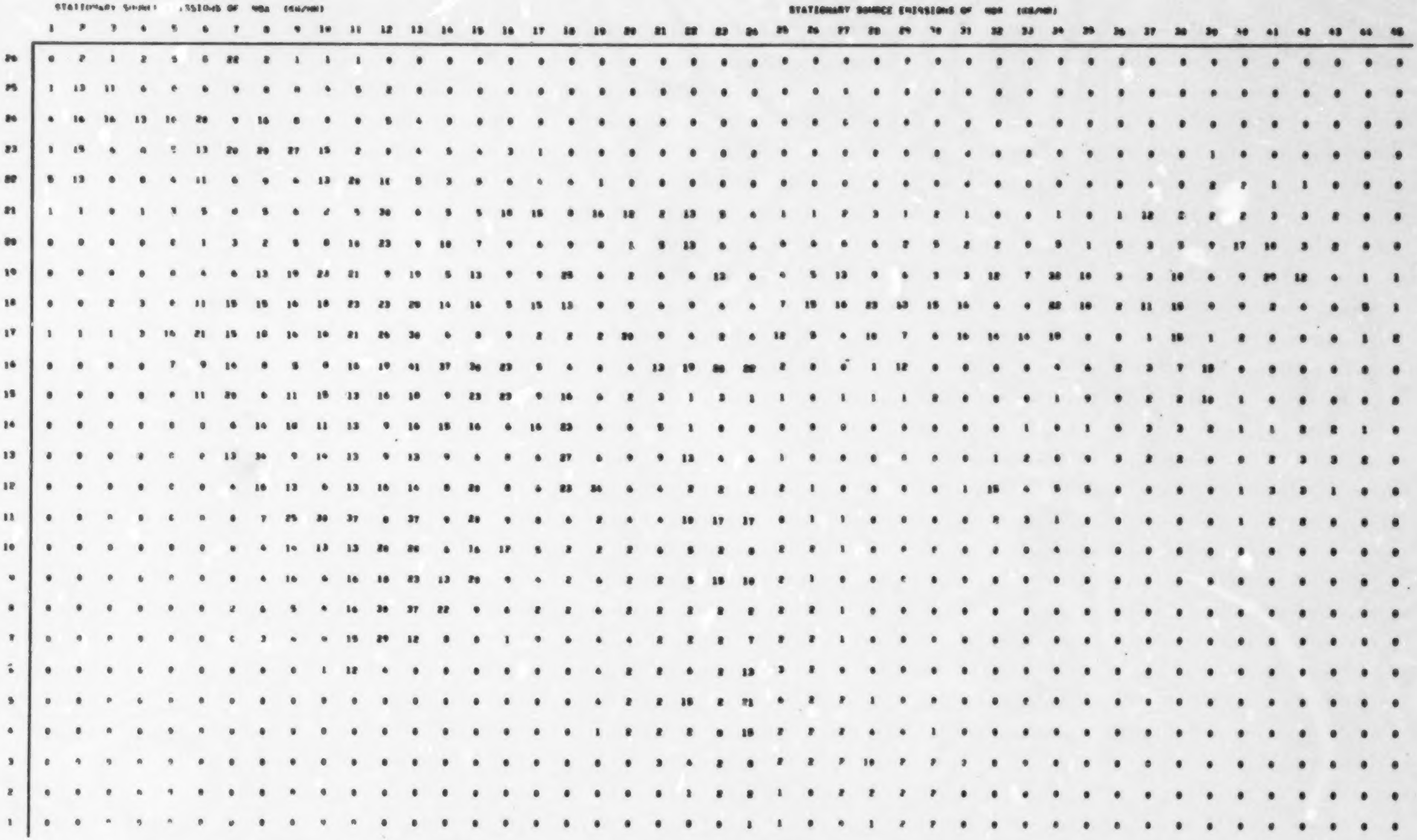
STATIONARY SOURCE EMISSIONS OF NOX (KG/HR)
STATIONARY SOURCE EMISSIONS OF NOX (KG/HR)

Figure A.17. Geographical Distribution of Stationary Source NO_x Emissions in 1971, kg/hr

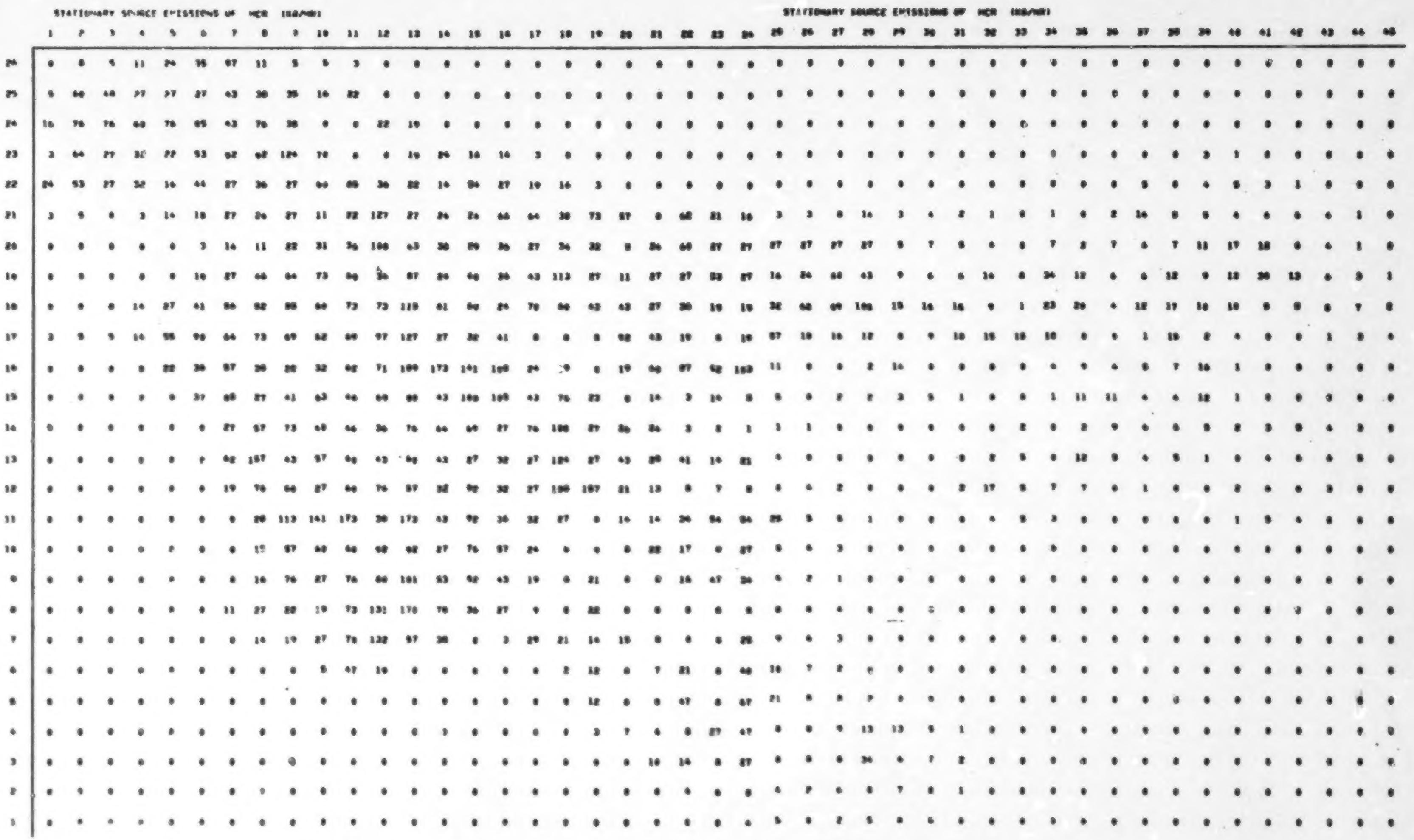

Figure A.18. Geographical Distribution of Stationary Source Reactive HC Emissions in 1971, kg/hr

average daily emissions are modulated by the time distribution function given in Table A.1 which allocates 80 percent of the daily total uniformly over the daytime hours (6:00 a.m. to 6:00 p.m. local time) and the remainder to the hours from 6:00 p.m. to 6:00 a.m.

APPENDIX B

TRAJECTORIES OF AIR MASSES USED WITH DIFKIN AIR QUALITY MODEL

The air trajectories shown in this appendix were used in the air quality computations performed with the DIFKIN air quality model. These trajectories were determined using meteorological data for September 29, 1969, a day in which an air pollution episode occurred in the Los Angeles Basin. See Ref. 1 for a description of the criteria used to obtain these trajectories.

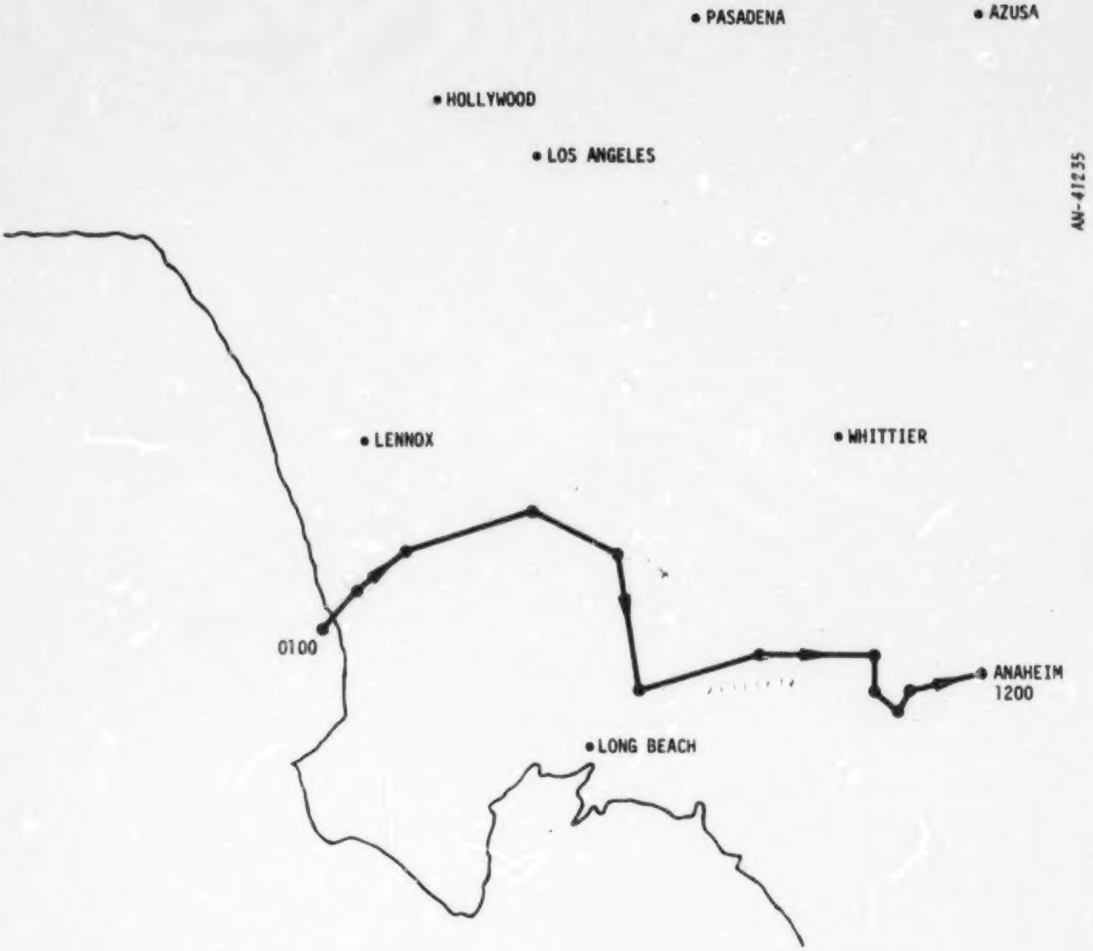
PASADENA
AZUSA
HOLLYWOOD
LOS ANGELES
AN-41235
LENNOX
WHITTIER
0100
ANAHEIM
1200
LONG BEACH

Figure B.1. Trajectory of Air Mass Arriving at Anaheim at 1200 PDT (Trajectory nodes are separated by one-hour intervals)

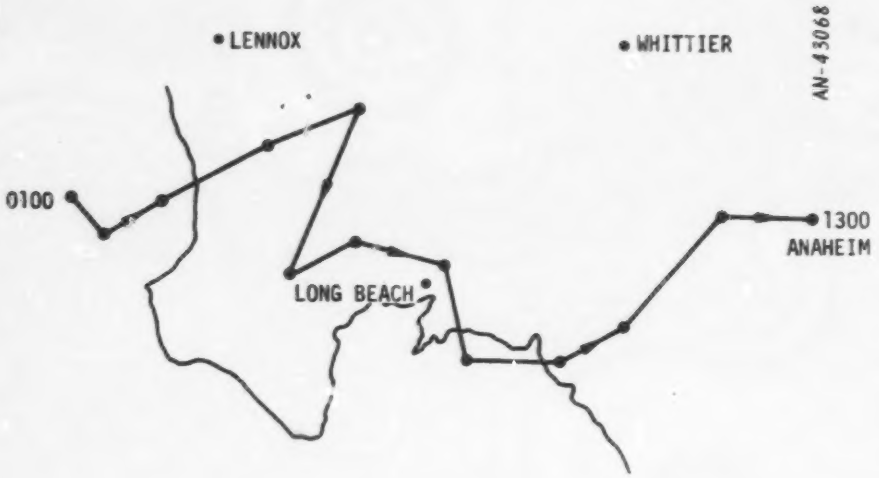
LENNOX
WHITTIER
AN-43068
0100
1300
ANAHEIM
LONG BEACH

Figure B.2. Trajectory of Air Mass Arriving at Anaheim at 1300 PDT
(Trajectory nodes are separated by one-hour intervals)

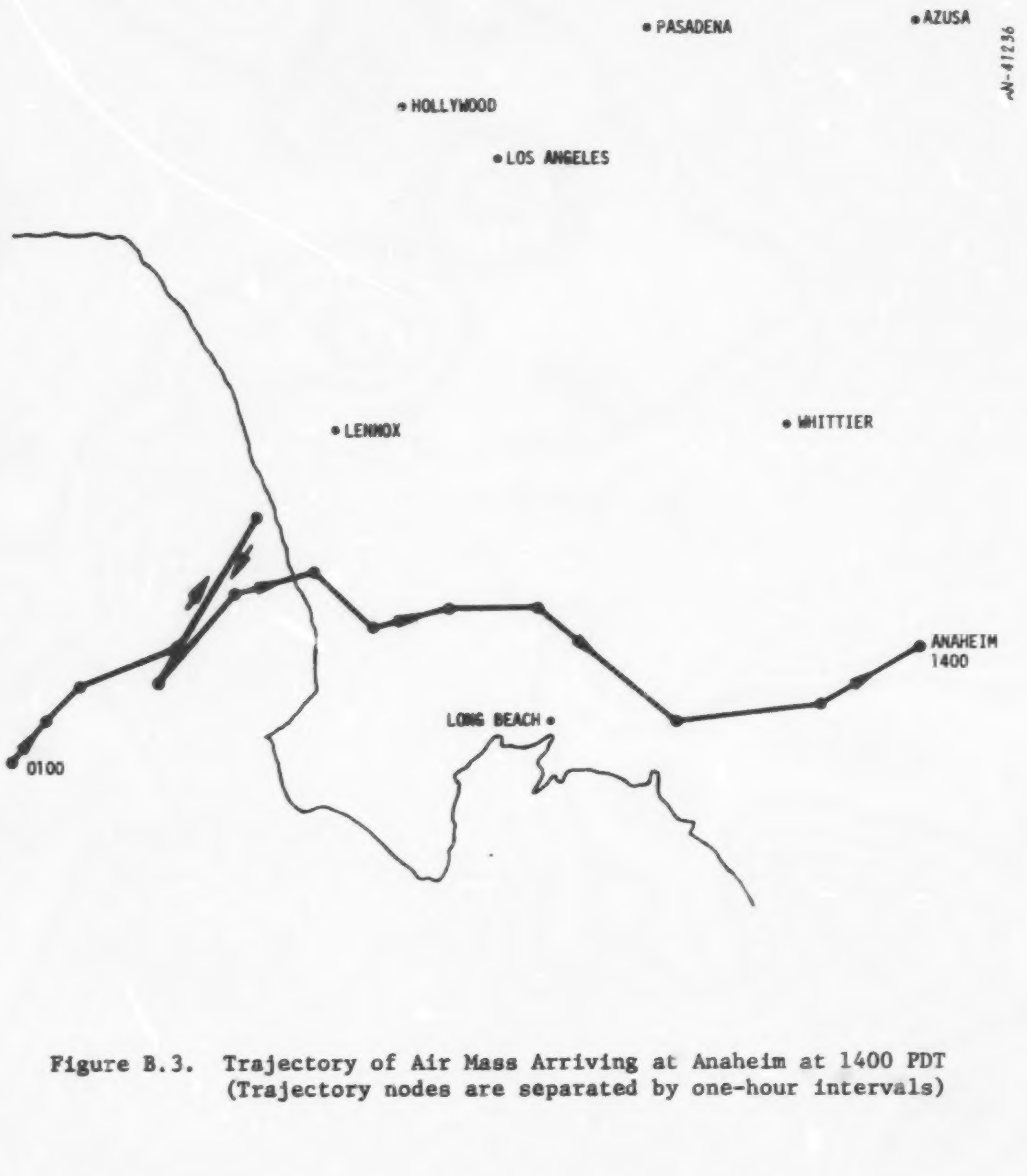
PASADENA
AZUSA
N-41236
HOLLYWOOD
LOS ANGELES
LENNOX
WHITTIER
ANAHEIM
1400
LONG BEACH
0100

Figure B.3. Trajectory of Air Mass Arriving at Anaheim at 1400 PDT (Trajectory nodes are separated by one-hour intervals)

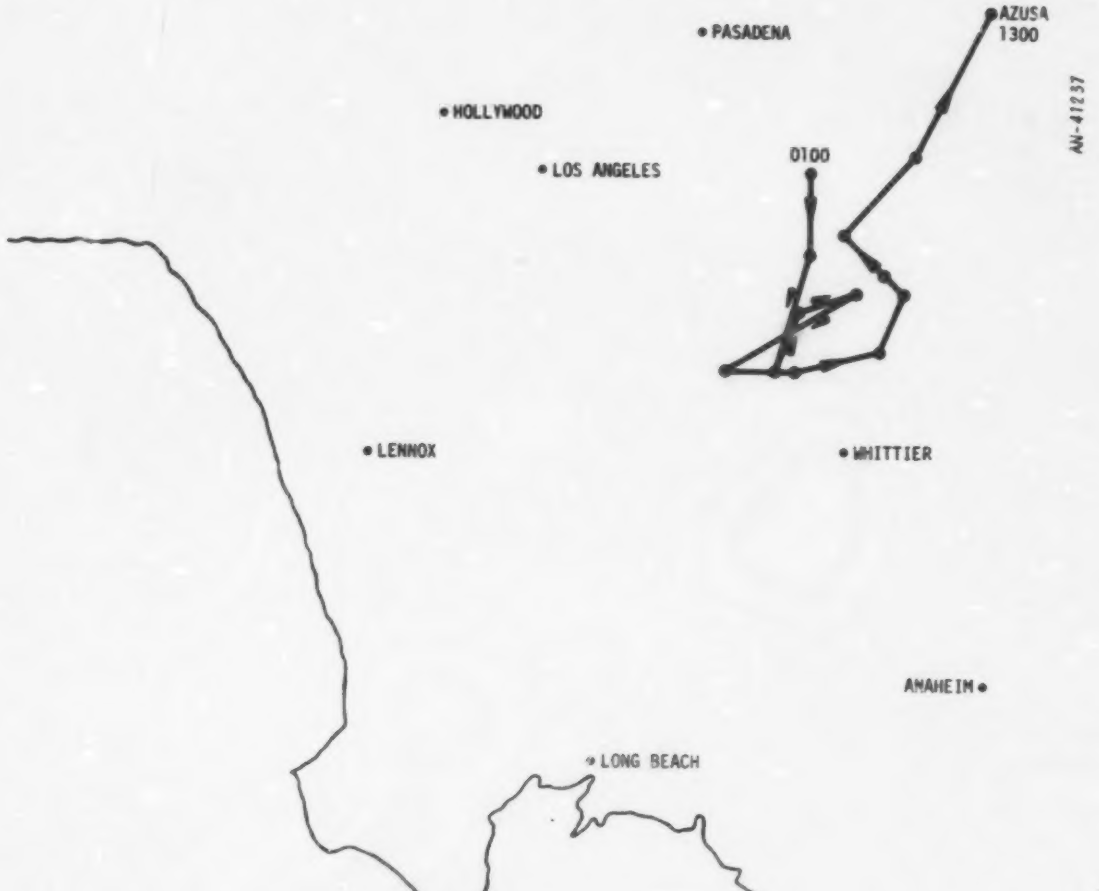
AZUSA
1300
PASADENA
HOLLYWOOD
LOS ANGELES
0100
LENNOX
WHITTIER
ANAHEIM
LONG BEACH
AN-41237

Figure B.4. Trajectory of Air Mass Arriving at Azusa at 1300 PDT
(Trajectory nodes are separated by one-hour intervals)

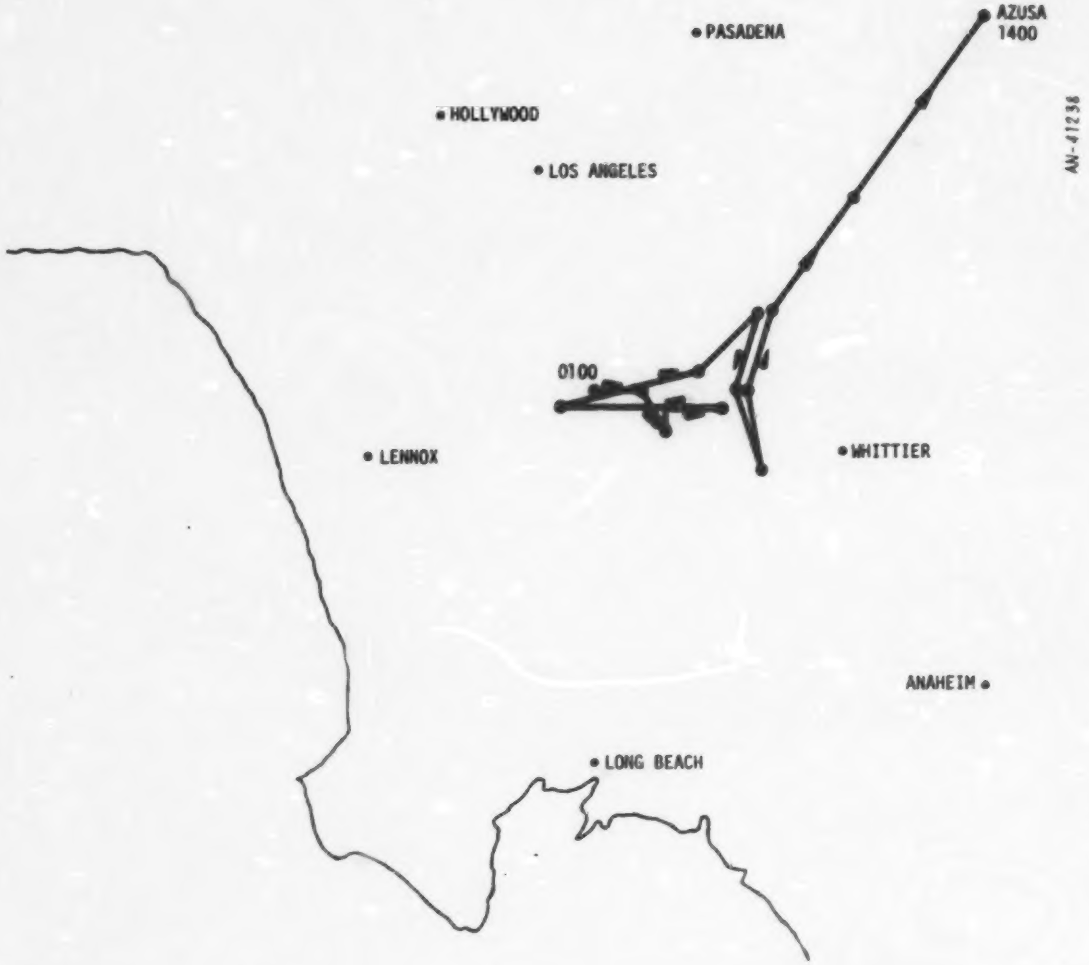
AZUSA
1400
PASADENA
HOLLYWOOD
LOS ANGELES
0100
LENNOX
WHITTIER
ANAHEIM
LONG BEACH
AN-41236

Figure B.5. Trajectory of Air Mass Arriving at Azusa at 1400 PDT (Trajectory nodes are separated by one-hour intervals)

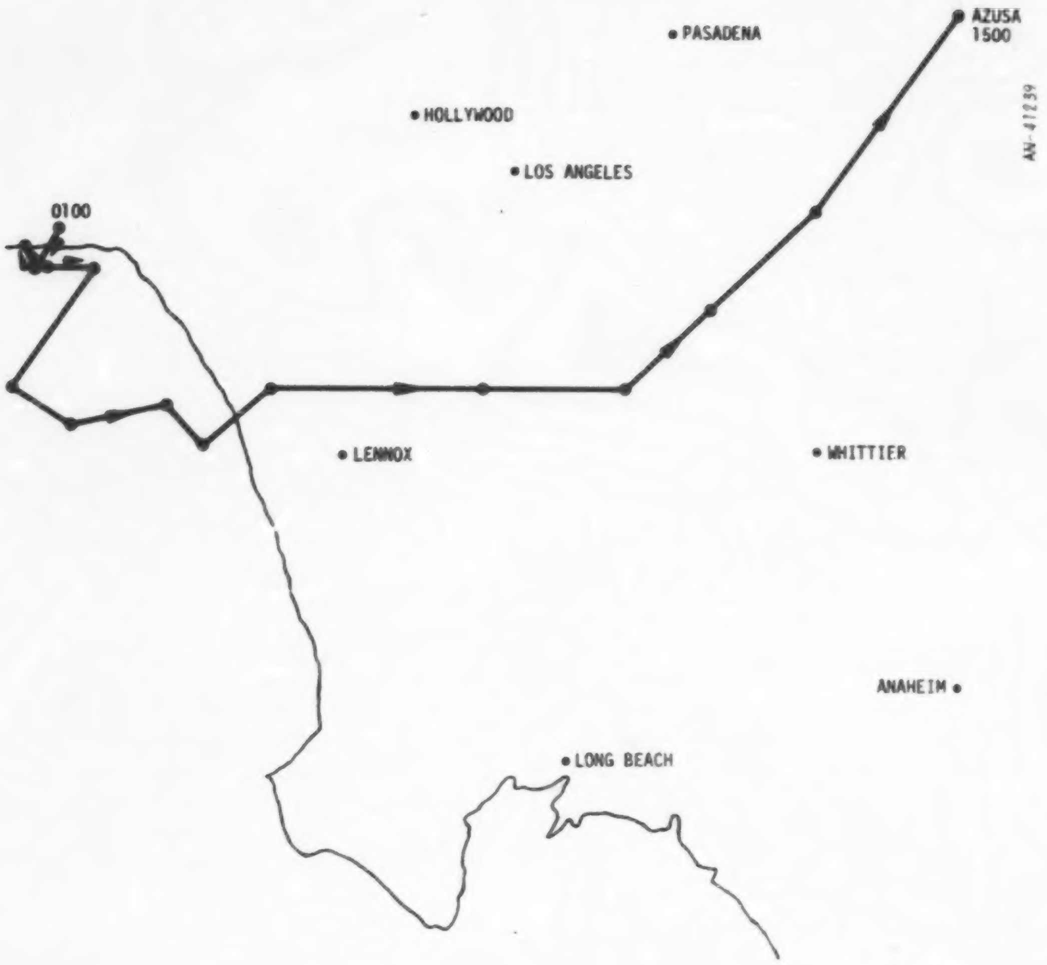
AZUSA
1500
PASADENA
HOLLYWOOD
AN-41239
LOS ANGELES
0100
LENNOX
WHITTIER
ANAHEIM
LONG BEACH

Figure B.6. Trajectory of Air Mass Arriving at Azusa at 1500 PDT
(Trajectory nodes are separated by one-hour intervals)

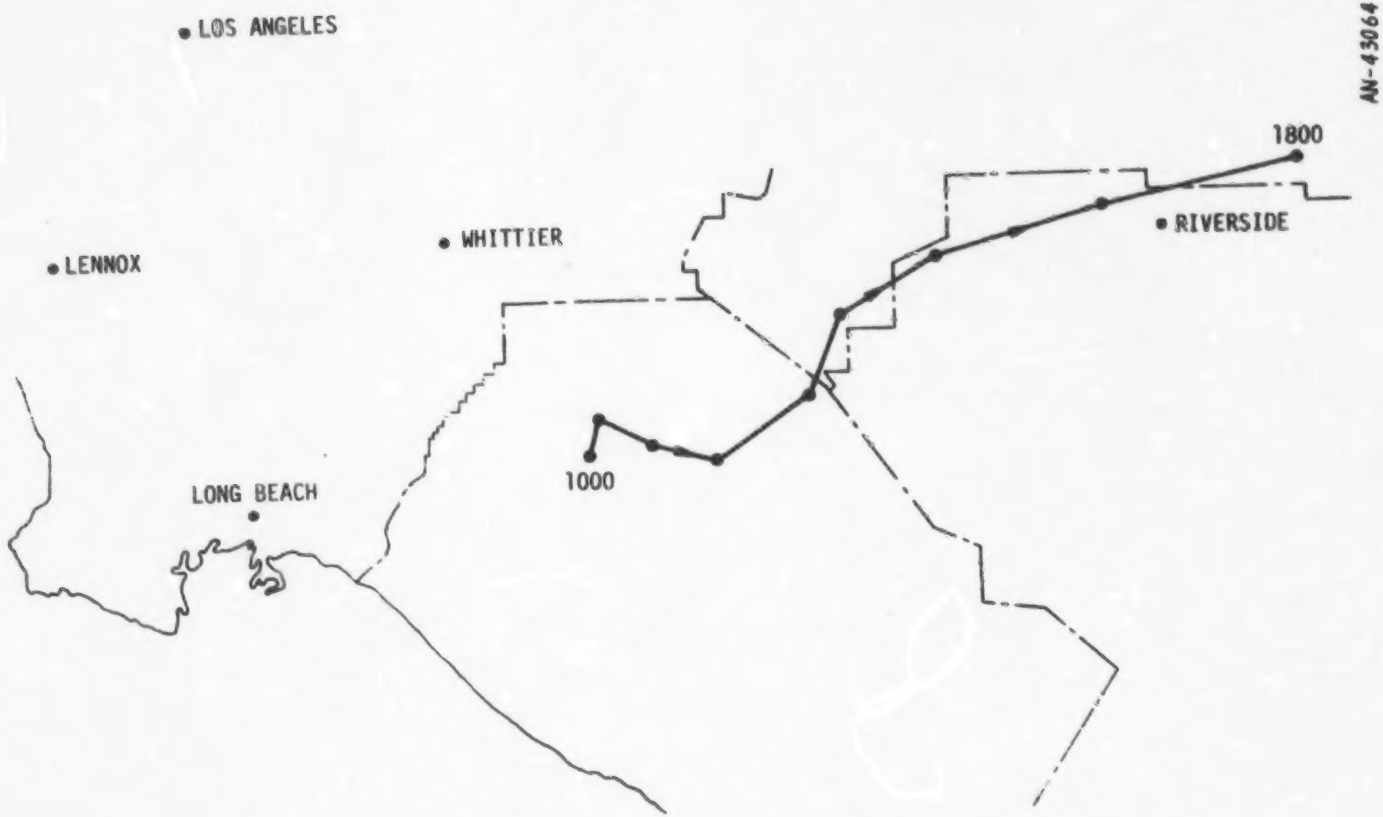
LOS ANGELES
LENNOX
WHITTIER
LONG BEACH
RIVERSIDE
1000
1800
AN-43064

Figure B.7. Trajectory of Air Mass which goes by Riverside and Starts in Orange County at 1000 PDT (Trajectory nodes are separated by one-hour intervals)

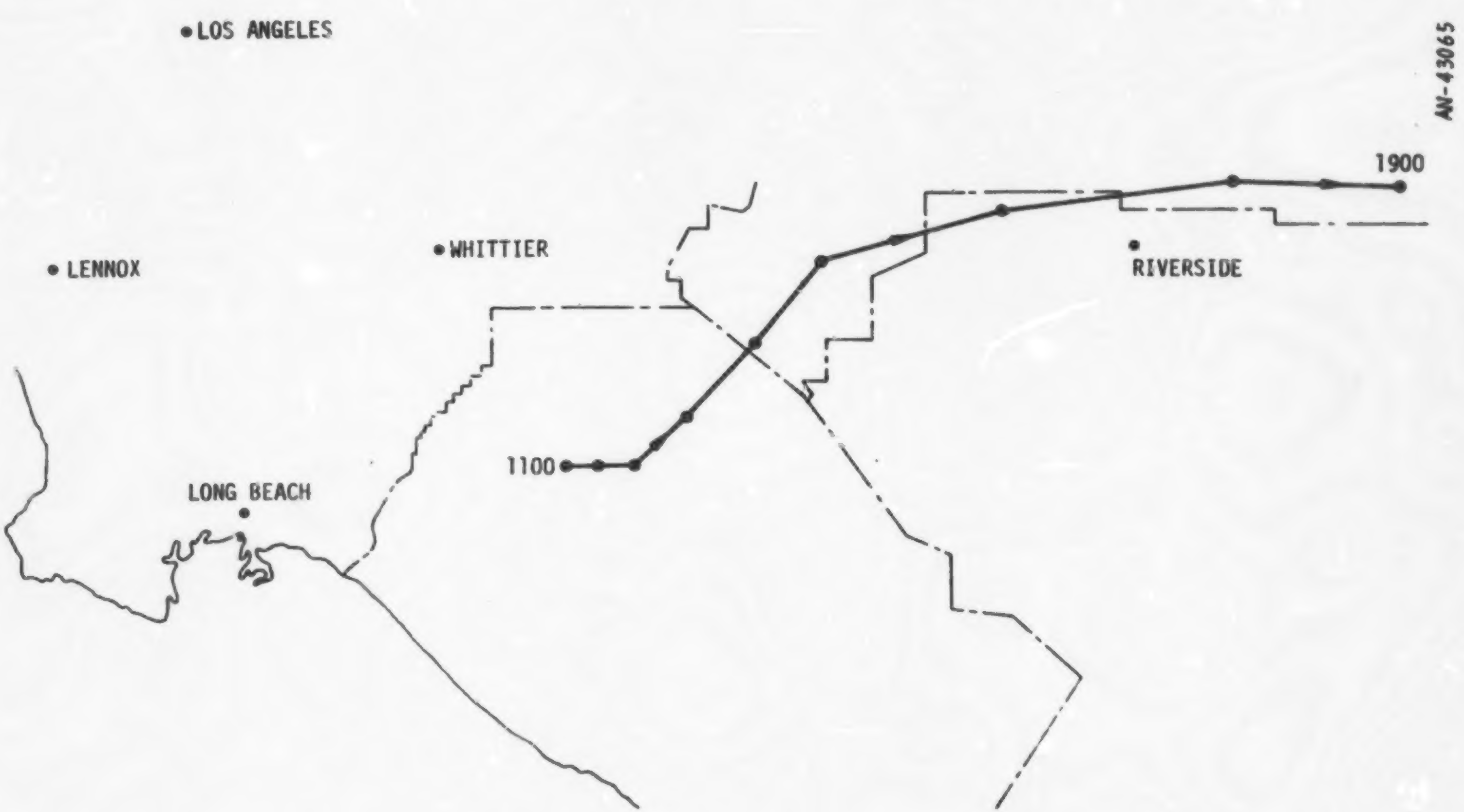
LOS ANGELES
LENNOX
WHITTIER
LONG BEACH
RIVERSIDE
1100
1900
AN-43065

Figure B.8. Trajectory of Air Mass which goes by Riverside and Starts in Orange County at 1100 PDT (Trajectory nodes are separated by one-hour intervals)

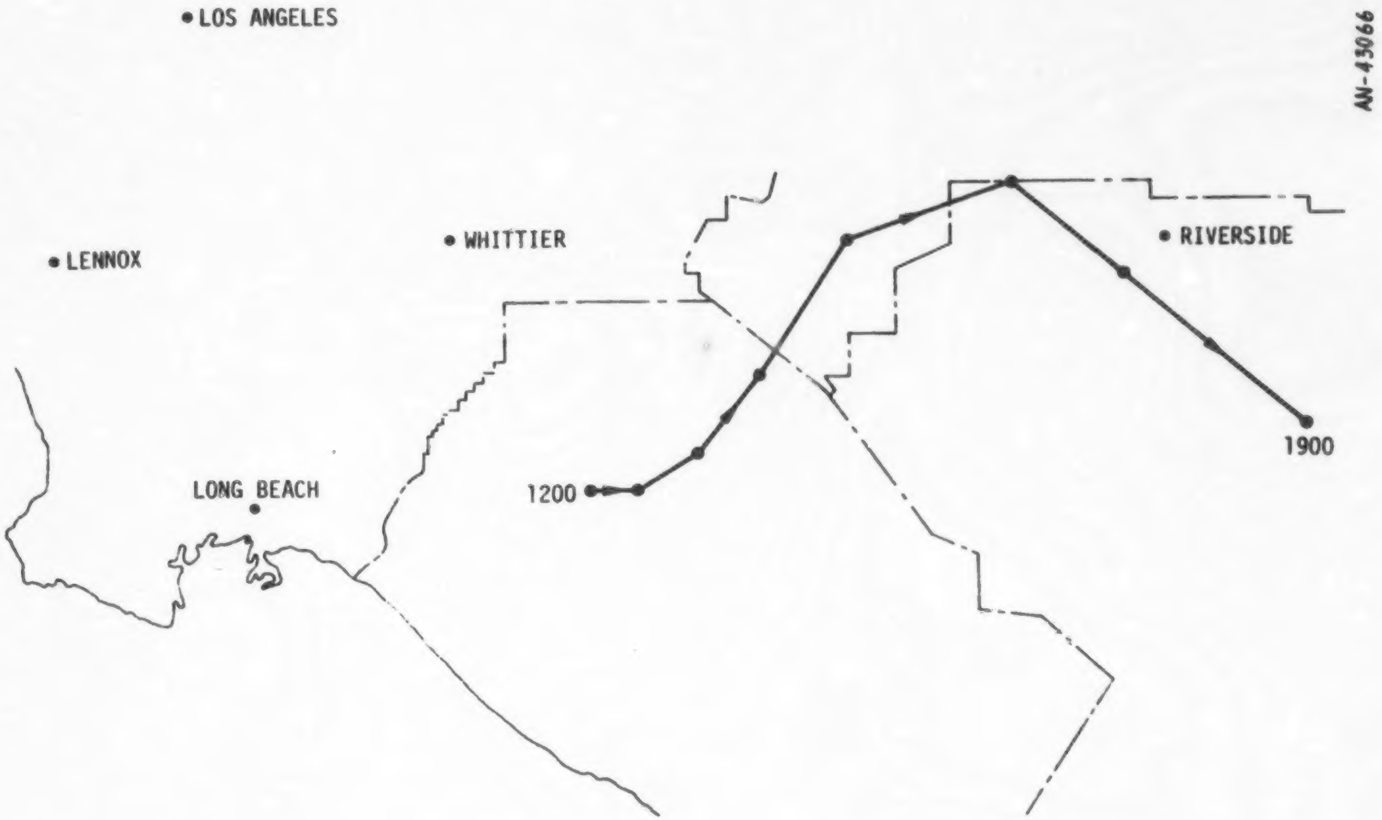
LOS ANGELES
LENNOX
WHITTIER
RIVERSIDE
LONG BEACH
1200
1900
AN-43066

Figure B.9. Trajectory of Air Mass which goes by Riverside and Starts in Orange County at 1200 PDT (Trajectory nodes are separated by one-hour intervals)

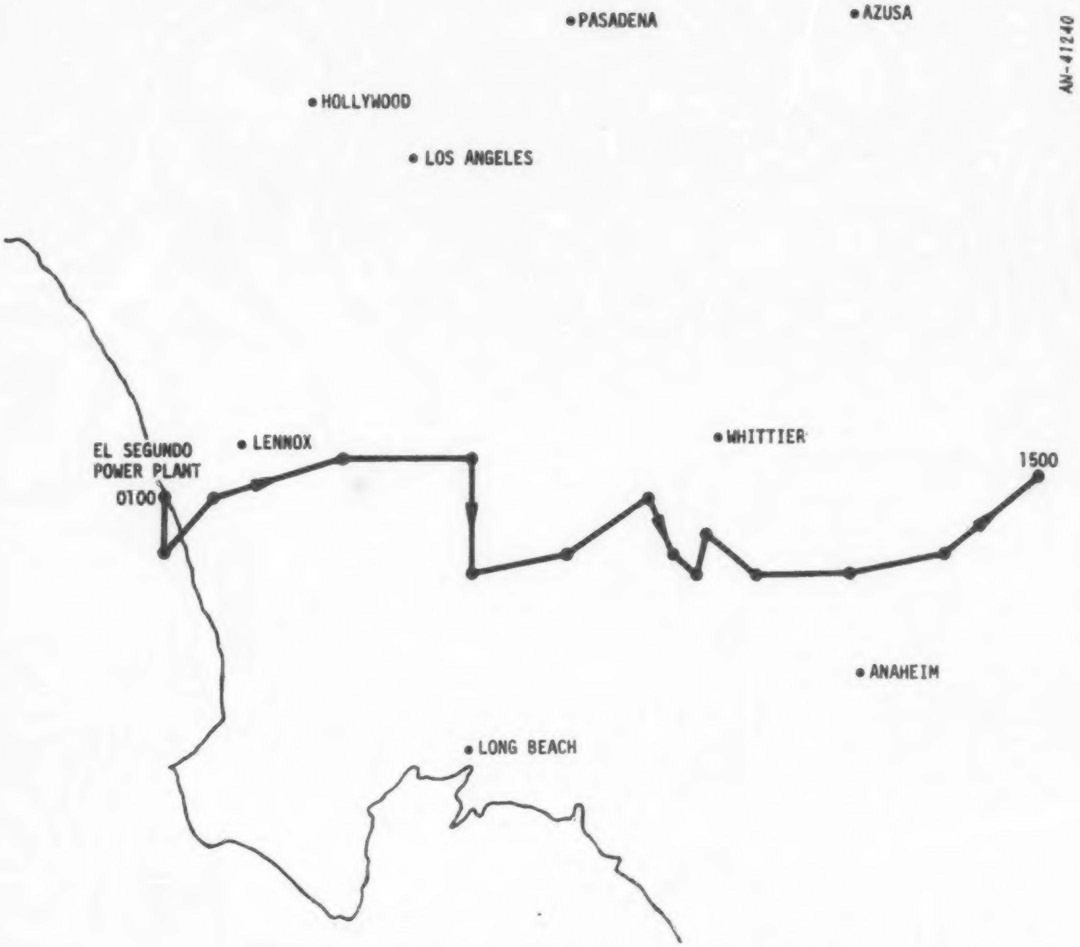
PASADENA
AZUSA
AN-41240
HOLLYWOOD
LOS ANGELES
LENNOX
WHITTIER
EL SEGUNDO POWER PLANT
0100
1500
ANAHEIM
LONG BEACH

Figure B.10. Trajectory of Air Mass Departing from El Segundo Power Plant at 0100 PDT (Trajectory nodes are separated by one-hour intervals)

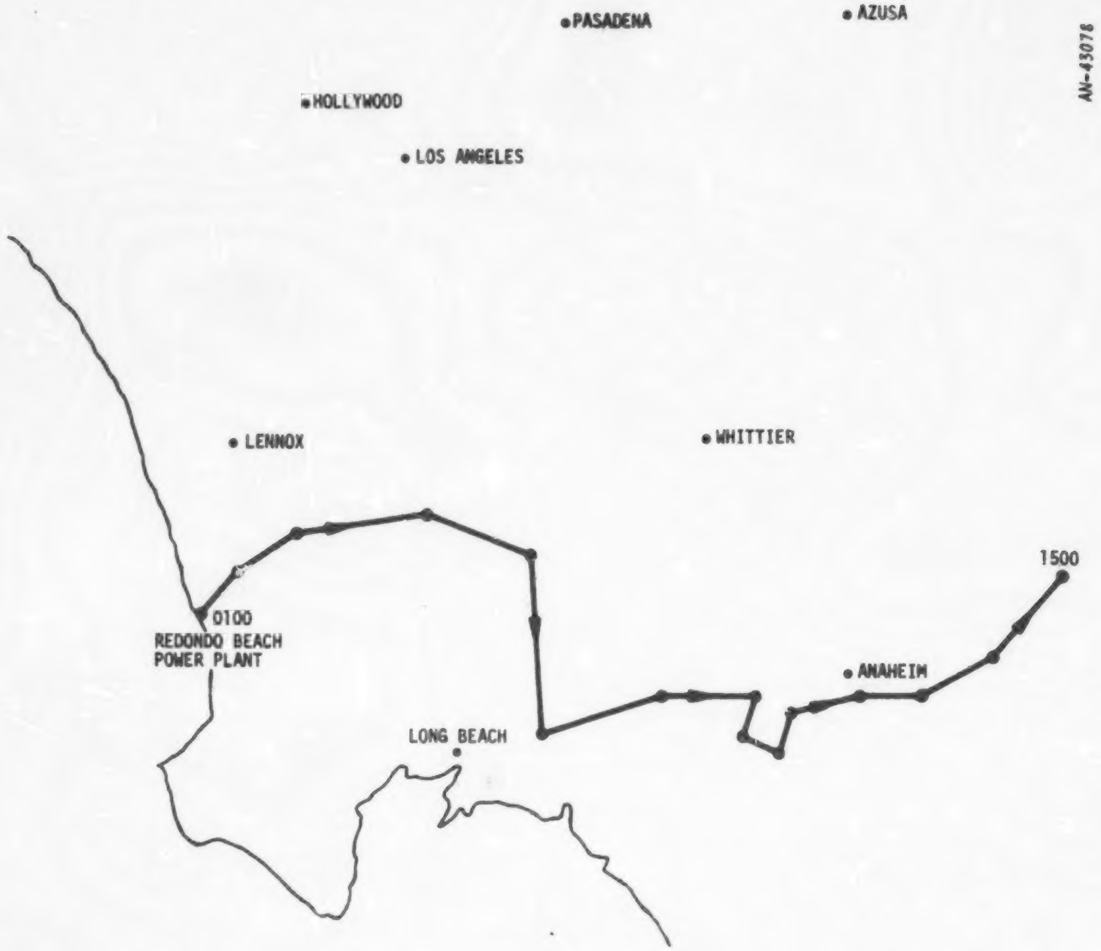
PASADENA
AZUSA
AN-43078
HOLLYWOOD
LOS ANGELES
LENNOX
WHITTIER
1500
0100
REDONDO BEACH
POWER PLANT
ANAHEIM
LONG BEACH

Figure B.11. Trajectory of Air Mass Departing from Redondo Beach Power Plant at 0100 PDT (Trajectory nodes are separated by one-hour intervals)

APPENDIX C

ADDITIONAL EMISSIONS ESTIMATES FOR STUDY AREA

This appendix contains the estimated emissions for 1970 which were used as the reference for the rollback calculations. Also presented are emissions estimates with and without electric cars for 1990 and 2000 for the scenario which assumes additional delays in the implementation of auto emission controls. Only the figures for NO, HC, and CO are given for these cases since the others are the same as shown in Tables 2.5 and 2.6 for the baseline cases and Tables 3.4 and 3.5 for the cases with electric cars. These correspond to the emissions for the case 1980d and have been depicted in Fig. 3.7 for nitric oxide. No air quality calculations were carried out for these cases.

TABLE C.1

STUDY AREA EMISSIONS FOR 1970-71

(Tons/Day)

	NO	HC	CO	SO_2	Particulates
Vehicular	455	918.4	9719.7	20.2	82.2
Stationary Area Sources	77.5	472.3	--	178	88.3
Power Plants	78.6	--	--	175	7.5
Oil Refineries	44.6	30.8	--	55.4	10.1
Total	655.7	1421.5	9719.7	428.6	188.1

TABLE C.2*

1990 BASELINE STUDY AREA EMISSIONS WITH DELAYED IMPLEMENTATION OF EXHAUST EMISSION CONTROLS FOR CONVENTIONAL CARS

(Tons/Day)

	NO	HC	CO
Vehicular	280.7	73.5	1103.4
Stationary Area Sources	140.8	160.7	--
Power Plants	116.2	--	--
Oil Refineries	53.7	37.1	--
Total	591.4	271.3	1103.4

---

*See Table 2.5.

TABLE C.3*

2000 BASELINE STUDY AREA EMISSIONS WITH DELAYED IMPLEMENTATION OF EXHAUST EMISSION CONTROLS FOR CONVENTIONAL CARS

(Tons/Day)

	NO	HC	CO
Vehicular	305.7	78.5	1166.9
Stationary Area Sources	181.1	160.7	--
Power Plants	98.1	--	--
Oil Refineries	57.6	39.8	--
Total	642.5	279.0	1166.9

---

*See Table 2.6.

TABLE C.4*

1990 STUDY AREA EMISSIONS WITH DELAYED IMPLEMENTATION OF EXHAUST EMISSION CONTROLS FOR CONVENTIONAL CARS AND 80% ELECTRIC CARS

(Tons/Day)

	NO	HC	CO
Vehicular	74.9	34.1	803.3
Stationary Area Sources	140.8	160.7	--
Power Plants	152.2	--	--
Oil Refineries	53.7	37.1	--
Total	421.6	231.9	803.3

---

*See Table 3.4.

TABLE C.5*

2000 STUDY AREA EMISSIONS WITH DELAYED IMPLEMENTATION OF EXHAUST EMISSION CONTROLS FOR CONVENTIONAL CARS AND 100% ELECTRIC CARS

(Tons/Day)

	NO	HC	CO
Vehicular	25.5	25.9	770.3
Stationary Area Sources	181.1	160.7	--
Power Plants	105.0	--	--
Oil Refineries	57.6	39.8	--
Total	369.2	226.4	770.3

---

*See Table 3.5.

APPENDIX D

THE LINEAR ROLLBACK FORMULA[2]

The rollback formula assumes that pollutant concentrations and emissions are proportional and is given by

$$R = \frac{(PAQ) - (DAQ)}{(PAQ) - (B)} \qquad (D.1)$$

where R = fractional reduction in emissions

PAQ = present air quality

DAQ = desired air quality

B = background concentration of pollutant

Thus the rollback formula purports to yield the reduction in emissions required to achieve the desired air quality, e.g., the air quality standard, given the current air quality and the background level of the pollutant, i.e., the concentration unavoidably present due to natural causes.

It should be noted that, since the air quality standards are set on a worst-case basis, a worst-case approach is implicit in using the rollback formula with the air quality standard as the desired air quality. Thus, for the present air quality (PAQ) we must use the highest concentration recorded in the region during the period of interest.

Caution is necessary in using the rollback equation to relate emissions and air quality. While the rollback approximation may fit some cases [e.g., carbon monoxide (CO)], its use for relating emissions and secondary pollutants such as nitrogen dioxide (NO_2) and ozone (O_3) is questionable because these two pollutants are produced by chemical processes which are highly nonlinear. The use of Eq. D.1 is also suspect

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even with highly reactive primary pollutants such as reactive hydrocarbons (HC) and nitric oxide (NO).

Since our aim is to determine the desired air quality (DAQ) levels given a current air quality (PAQ), the background level (B), and the fractional reduction in emissions (R), we must solve for DAQ in Eq. D.1, which yields

$$\mathrm{DAQ} = \mathrm{PAQ}(1 - R) + RB \qquad \text{(D.2)}$$

In using Eq. D.2, the factor PAQ would be the baseline air quality level with no electric car use. The factor R would be determined by the emissions reduction caused by the increasing use of electric vehicles.

One difficulty in using Eq. D.2 is that the baseline air quality (PAQ) for 1980, 1990, and 2000 is not readily available. Two approaches may be followed to circumvent this problem. The first is to predict the baseline air quality by means of Eq. A.2 itself. This would be done by using for PAQ the known air quality for a previous year such as 1970, and estimating R from

$$R = 1 - \frac{E_k}{E_{1970}} \quad ; \qquad k = 1980, 1990, 2000$$

where E_k are the baseline emissions for the year k. The second approach is to use the values the GRC model predicts as the baseline air quality levels for 1980, 1990, and 2000. This has the advantage of providing a common starting point for the air quality impact analysis for both the GRC model and the rollback formula. Both approaches have been used and compared in the text.

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TASK REPORT 8

PARAMETRIC ENERGY, RESOURCE, AND NOISE IMPACTS OF ELECTRIC CARS IN LOS ANGELES

A.R. Sjovold

ABSTRACT

Widescale use of electric cars in the South Coast Air Basin (SCAB) as alternatives to conventional autos can reduce the consumption of primary energy that otherwise might be used in auto travel. The degree of reduction depends strongly on future improvements in gasoline fuel economies for conventional autos. The battery recharge energy requirements for a 100% SCAB electric car population can potentially be accommodated within the forecast capacity of the SCAB electrical utilities if the electric cars are recharged during the normal off-peak period. In this mode prior to 2000 recharging would be associated with the use of oil-fired steam-electric plants in the basin on high demand days. During low-demand periods significant amounts of recharge energy would come from coal, gas, and, to a lesser extent, nuclear generation such that over the year substantial savings in petroleum might be obtained.

For large SCAB electric car populations, significant additions to total U.S. demands of some materials will occur, depending on the battery technology employed. Critical material demands in this respect are nickel for nickel-zinc batteries, and lithium and graphite for lithium-sulfur batteries.

For a largescale nationwide implementation, critical material demands to be considered are for lead, antimony, nickel, titanium metal, lithium, and graphite. It is assumed that all of the metals will be highly recycled.

Electric cars also possess the potential of decreasing community noise levels arising from urban traffic. Potential reductions in noise intrusions appear more significant than reductions in general background noise levels.

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SUMMARY

Potential impacts of electric car use on energy consumption, material supplies and demands, and community noise are analyzed. The primary impacts are related parametrically to electric car use only in the South Coast Air Basin of Califronia (Los Angeles region) and cover the years 1980 to 2000.

Electric cars as alternatives to conventional autos have the potential of reducing the consumption of primary energy. For both alternatives a significant source of primary energy prior to the year 2000 will be crude oil, with electrics being somewhat more efficient in converting crude oil to vehicle-miles than the average conventional auto of the future. The degree of reduction depends on future battery technologies for the electrics, and improvements in gasoline mileage for conventional cars. For 100 percent electric car population in the year 2000, utilizing advanced battery technology, primary energy consumption for automotive travel would be two-thirds of the 1974 level. Conventional-auto gasoline mileages would have to more than double to obtain the same reduction. Further reductions are possible with electric cars if future power plant efficiencies should rise above the existing 36 percent for Southern California Edison (SCE) oil fired plants.

The battery-charging requirements for a 100 percent electric car population can be met with the existing and forecast unused off-peak generating capacity. No new power plants need be constructed for this purpose in the South Coast Air Basin beyond the additions already planned by utilites in the Basin.

High levels of electric car usage in SCAB can cause significant increases in total US demands for at least some of the materials associated with any given battery alternative. Estimated impacts on materials

8.1.F

resources are summarized on the next page. Existing technology with lead-acid batteries will significantly increase demands for lead and antimony, even at high recycle rates. Nickel-zinc batteries will increase demands significantly for nickel and much less so for zinc. Zinc-chlorine batteries will impact zinc demands even less, but they impose significant demands on titanium metal supplies. However, titanium metal is a very small fraction of total titanium demands, so that electric car demands are not significant in terms of total titanium demand. Lithium-sulfur batteries will cause significant increases in demands for lithium and graphite.

The assessments assume that the following materials will be highly recycled if employed in electric car batteries: lead, antimony, nickel, zinc, metallic lithium, and metallic titanium. Of these materials, the US is self-sufficient only in lithium. However, world reserves of all the other materials appear adequate to support 100 percent electric car usage in SCAB. World reserves are inadequate to support a nationwide electric car implementation utilizing lead-acid batteries. They are most ample to support nationwide implementations with lithium-sulfur batteries, and appear adequate to support nationwide implementations with either zinc-chlorine or nickel-zinc batteries.

Electric cars should prove to be quieter than the conventional autos they replace. Large-scale usage of electric cars should cause perceptible decreases in background traffic noise levels, and significant reductions in peak auto noise intrusions.

SUMMARY OF RESOURCE IMPACTS

Battery Type	Material	Quantities, Thousands of Tons per Year: US Primary Production 1968	US Primary Production 2000 (Range)	US Primary Demand 1968	US Primary Demand 2000 (Range)	Equilibrium* Annual Electric Car Requirement for New Material with 2-Year Battery Life and 90% Recycle (SCAB)	Usage Conditions (SCAB Level and Year)	Potential Problem ((Electric Car Requirement as Percent of National Primary Demand for Given Usage Year)): SCAB Implementation	Nationwide** Implementation
Lead-Acid	Lead	354	520-1,120	880	1,300-2,800	22	17%, 1980	1.7%	33%
	Antimony	1.9	2.5-4.8	21.1	28-52	0.6	17%, 1980	2.1	43
Nickel-Zinc	Nickel	15	36-52	160	382-550	29	46%, 1990	7.8	157
	Zinc	529	786-1,500	1,406	2,040-4,000	20	46%, 1990	0.8	16
Zinc-Chlorine	Zinc					12	100%, 2000	0.4	8
	Titanium (metal)	305 (0)	670-1,610 (0)	440 (13)	960-2,160 (62-234)	9.5	100%, 2000	0.6	12††
	Chlorine	8,400	26,400-43,900	8,400	26,400-43,900	130†	100%, 2000	0.4	8
Lithium-Sulfur	Lithium	2.9	9.4-14.4	2.6	8.7-13.1	3.2	100%, 2000	29††	587††
	Graphite†	3.0	4.0-4.7	60	80-135	43†	100%, 2000	40	800
	Sulfur†	11,000	28,000-45,000	10,000	26,000-41,500	130†	100%, 2000	0.4	8

---

[*] Equilibrium conditions for the fraction of electric cars in the total population are assumed; that is, the electric car population fraction is relatively constant and not undergoing any long-term buildup.

[**] The scaling factor to be applied to the "Annual Requirements" column for nationwide electric-car use is approximately 20.

[†] No recycle assumed.

[††] Electric car requirements for these materials would impact on production capacity for metallic forms.

8-1-4

1 INTRODUCTION

Electric cars replacing conventional autos have been suggested as possible solutions to pressing urban problems such as air pollution and the growing rate of energy consumption. Several analyses[1-3] have pointed to the potential for electric cars, especially with improved battery technology, to alleviate our energy supply problems. However, the ultimate impacts of electric cars on energy supply, air pollution, and economic resources are not readily deduced. They will depend on future conditions and the ways in which electric cars come into general use.

The objective of this paper is to estimate the likely impacts of electric car sales and use on energy consumption, material resources, and urban noise. The analyses are part of a comprehensive impact study of electric cars, focusing on the South Coast Air Basin of Southern California and covering the years 1980 to 2000. This paper depends on several previous tasks of this study that produced forecasts of population, energy, transportation, electric car technology, and future economic conditions.[*] It also depends strongly on a companion study task[**] which developed alternative scenarios governing the introduction and operation of electric cars in the South Coast Air Basin, with corresponding estimates of sales and use. Additional work, largely based on Ref. 10, gave a qualitative assessment of all potential electric car impacts, and thereby provided an additional basis for the more quantitative assessments presented in this paper.

The impact assessments presented here focus strongly on a system of battery-powered electric cars which are used daily and recharged primarily at home during the night. No new electric power plants, beyond those already forecast, are likely to be required; the recharging during off-peak periods may utilize generation from several types of power plants (e.g., coal, gas, nuclear) but will rely strongly on local oil-burning power plants, especially during peak demand days. The electric cars are expected initially to fulfill a "second car" role, utilizing lead-acid batteries. Future battery developments may center on several alternatives--nickel-zinc, zinc-chlorine, or lithium-sulfur--which promise to provide from three to ten times the specific energy storage of lead-acid batteries.

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[*] Task Reports 1-5 (also Refs. 4-8).

[**] Task Report 10 (also Ref. 9).

Although cars with lead-acid batteries may find early acceptance by a small fraction of the auto buying public, their limited ranges will likely prevent them from ever achieving wide acceptance. Consequently, large-scale use of electric cars must rely on the later development of better batteries. Likely scenarios therefore involve mixes of battery technology within the electric car population. Furthermore, it is not certain that advanced batteries can directly replace earlier ones. For example, the configuration of a high-temperature lithium-sulfur battery system is likely to be quite different from that of a lead-acid battery system.

As a matter of convenience in this paper, and in general accord with its parametric character, we have avoided the ticklish question of just how and when one steps from one battery technology into the next. Instead we first establish the electric car energy and resource requirements, as functions of the level of electric car population and usage, for a given electric car technology. These parametric relationships are then used to assess the energy and resource impacts of each of the electric car usage scenarios developed in Ref. 9. In the calculation of these impacts, it is assumed that only "pure" systems (no mix of electric car technologies) are employed in each specific time frame. This leads to clearly-defined and useful results, but admittedly may be less than realistic. It seems preferable, however, to basing impact calculations on detailed schedules of technological and marketing progress, which must be arbitrary in nature because they cannot be accurately forecast.

The assessment of electric car impacts in this paper begins in Sec. 2, with an analysis of the impact on energy supply and demand in the South Coast Air Basin (SCAB). The analysis includes effects on total primary energy, auto transportation energy, electric energy, and gasoline demand. Section 3 treats impacts on resources, primarily the materials to support the alternative battery technologies. Section 4 deals with the impact of electric car usage on vehicle-generated noise and its contribution to urban noise.

Impacts on air quality and the economy are treated in companion study tasks. Social and cultural impacts are intimately interwoven with the considerations and evaluations involved in the development of scenarios for electric car sales and usage, and are therefore treated in the study task reported in Ref. 9.

2 ENERGY IMPACTS

The source of primary energy for energizing electric cars in the South Coast Air Basin has already been identified.[5,10] Under all demand conditions in 1980, off-peak generation for recharging electric cars will come from oil-fired plants in the basin. In 1990, off-peak generation during high demand seasons will be predominantly from oil, while low-demand seasons will make available some off-peak generation from coal and gas fired plants. In 2000, off-peak generation will come from several sources during both high and low-demand seasons, with oil-fired plants the last to be used at high levels of electric car usage. Oil-based generation will be an important, though declining source, of recharge energy throughout the forecast period. Present and future autos, some of which would be displaced by electric cars, would depend on the same source, oil; indeed the same refineries produce all the required products--distillate and residual fuel oils for power plants, and high-octane gasolines for internal combustion engines. Consequently, the analysis of the impact on primary energy identifies the changes in required crude oil supply and traces the path of energy flow through the refinery to each end use.

2.1 PRIMARY ENERGY

2.1.1 Refinery Operations

A modern refinery represents a complex process which is capable of adjusting the relative outputs of gasolines, fuel oils, and other products over a wide range to suit demand. The simplest (and least energy-consuming) process is the separation of the crude oil into its natural constituents by fractional distillation. Unfortunately, the yields of the various fractions depend on the nature of the source crude; fractionation usually does not yield sufficient automotive gasoline. However, simple fractionation would undoubtedly provide ample product for power plant fuel oil, if that were the primary product needed. To increase the amount of high-octane gasoline, processes such as catalytic reforming and cracking, thermal cracking, polymerization, and alkylation are added (along with an increased energy input).

According to data reported by Stanford Research Institute,[11] refineries in California produced 42 percent of their total product as motor gasoline in 1970. Based on SRI's data, the total energy output of the refineries as useful products was 88 percent of the total energy input (crude plus external energy). Thus the refineries were running at 0.88 overall thermal efficiency. Another study[12] indicates that the average difference for US refineries between energy input and energy output is 11 percent, for an overall thermal efficiency of 0.89.

It is difficult to allocate the energy used in refining among the products, although it is the relatively high demand for automotive gasoline which establishes the need for the more energy-consuming processes. In one study,[13] refinery energy input was allocated as a constant percentage to all end products. That is, the efficiency was taken to be the same for power-plant fuel as for gasoline. However, the same study used a quite different allocation in dealing with refinery pollutant emissions, indicating that 82 percent by weight of refinery air emissions are associated with the catalytic cracking processes, and only 0.3 percent with vacuum distillation. Emissions, of course, do not precisely correspond to energy consumption; nonetheless, the data strongly suggest that the catalytic cracking process, which is important for increasing gasoline yield, is the most significant energy consumer in the refinery.

As we have indicated in a previous study task,[10] a more equitable allocation of energy consumption might be based on the requirements for single-purpose refineries. It is feasible with modern hydrocrackers to obtain a 90 percent yield of high-octane gasolines; however, we know of no refineries that operate on this basis, and consequently cannot estimate the overall thermal efficiency of such an operation. If the entire refining energy loss is allocated to gasoline production, then gasoline refining is only 75 percent thermally efficient (at a product fraction of 42 percent and an overall efficiency of 0.89). However, it is not reasonable to assume that the other refinery products are obtained free of any energy losses. Therefore, we have assumed for comparative purposes that it takes roughly 10 percent more energy to refine gasoline than power-plant fuel oil. Consequently, at a gasoline product fraction of 42 percent and an overall refinery efficiency of 0.89, the corresponding product efficiencies in refining would be 0.84 for gasoline and 0.93 for power plant fuels. Other studies[1-3] of the comparative efficiencies of electric cars and conventional cars have assumed gasoline refining efficiencies of 0.74 to 0.87.

In the comparisons of overall energy consumption rates between electric and conventional cars that follow, only the relative refining efficiency of 0.9 is used (gasoline refining efficiency divided by fuel oil refining efficiency). Thus in absolute terms the estimates of energy consumption for both cars are low by about 7 percent in accounting for total refinery energy losses. Also, the energy consumed in extracting the oil and transporting it to the refinery has not been included in our comparisons, since these energy losses are common to the use of either vehicle.

2.1.2 Energy Used in Transporting Fuels

For refined fuels, the energy used in transporting them to gasoline jobbers or power plants may be appreciable if distances are long. In the South Coast Air Basin, however, there are many refineries and hence distances are short. It is assumed in this paper that both gasoline and power plant fuel are transported by truck. A study by Hirst[14] shows that average inter-city freight hauling uses 2,340 Btu per ton-mile. In-city hauling may have a slightly greater energy consumption rate. However, assuming the inter-city energy consumption rate, a 50-mile trip (probably a reasonable estimate for SCAB) would require 117,000 Btu to carry a tone of gasoline, which contains about 42 million Btu. Thus such a short trip consumes less than 0.3 percent of the energy that is delivered. Because of the proximity of refineries to both power plants and ultimate gasoline sellers in SCAB, energy transport costs are small and the differences are smaller yet. Thus this energy cost is assumed to be insignificant for comparative purposes.

2.1.3 Energy Conversion Efficiencies

There have been several other investigations that compared electric car energy consumption with that of conventional autos. Each analysis proceeds from certain assumptions regarding the stepwise efficiencies in the conversion of primary energy to the ultimate delivery of road miles under some assumed driving scenario.

In one of these studies,[1] a comparison under steady speeds showed electrics to be 1.5 times more efficient in consumption of primary energy. However, the battery recharge efficiency was not included and the study assumed vehicles of roughly comparable weight, whereas the 1980 electric car of our study is substantially heavier than the compact car it is assumed to replace.

The other two studies[2,3] also had varying assumptions regarding the efficiencies in each step of the energy flow and the scenarios for electric car use, with conclusions that electrics could perform anywhere between equal and twice the efficiency of conventional gasoline-powered autos.

In this analysis we will rely on the baseline projections developed in Ref. 6 and the electric car configurations described in Ref. 7 to guide the calculation of comparative energy consumption rates for electric and conventional cars. Significant conditions established for the baseline projections are:

- Gasoline-powered vehicles, in response to economic and/or legislative forces, will achieve improved gasoline mileage (for the average new car) of 15.5 mpg, 22.0 mpg, and 25.0

mpg by 1980, 1990, and 2000 respectively. This will yield average mileages (for all cars in the population) of 13.75 mpg, 20.0 mpg, and 24.0 mpg respectively.[6]

- The present average gasoline mileage is taken as 12.5 mpg.
- These gasoline mileages are appropriate in characterizing all trip-making within SCAB.

In addition, we will assume for the parametric analysis of impacts that the electric cars will replace IC cars with the above stated average gasoline mileages. This assumption will provide for accurate assessments at high electric car usage levels. However, at low levels of electric car usage, especially in the introductory period (early 1980s), electric cars will likely be chosen as alternatives to small compact or sub-compact cars which achieve gasoline mileages in the range of 20 to 30 mpg. Later versions of electric cars with more advanced battery technology, may be chosen as alternatives to a wider range of IC cars than just sub-compacts or compacts; especially so if conventional cars are to achieve the improved gasoline mileages we have postulated. One approach will undoubtedly rely on lowering the weights of the heavier, full sized IC autos; thus future electric cars will be closer in size and weight to a greater number of future IC cars.

In accord with these assumptions, energy consumption rates for converting primary energy to road miles for conventional auto use in SCAB are shown in Table 2.1.

Energy consumption rates for electric cars will depend on the thermal efficiency of power-plant energy conversion, electric power transmission losses, battery recharge and discharge efficiencies, and electric motor and power train efficiencies. In Ref. 5 it was shown that the average efficiency of oil-fired power plants in the South Coast Air Basin is presently about 36 percent (substantially higher than the 1972 national

TABLE 2.1

AVERAGE ENERGY CONSUMPTION RATES ASSUMED FOR GASOLINE-POWERED AUTOS*

Present	11,000	Btu/mi
1980	10,000	Btu/mi
1990	6,875	Btu/mi
2000	5,729	Btu/mi

---

*Includes 10 percent energy surcharge for refining gasoline relative to power plant fuels, and gasoline energy content of 125,000 Btu/gal.

average of 32 percent) and is expected to remain at or slightly above that level essentially through the period of interest for this study. Also indicated in Ref. 5 is the very likely prospect that oil-fired plants would be used most frequently throughout the period 1980 to 2000 to generate the necessary power during off-peak hours to recharge the electric cars. However, by the year 2000 it may be necessary to provide some of the off-peak power for electric car recharge by firing out-of-basin coal-fired plants. This is expected to be a minor fraction of the required recharge energy for significant levels of electric car usage, and the coal-fired plants will not be significantly different in conversion efficiency from the 36 percent assumed for in-basin plants. Consequently, it will be assumed that conversion of fuel oils to electric energy for electric car recharge will be accomplished at 36 percent efficiency or 9500 Btu/KWH.

Detailed planning data of the Southern California Edison Co. (SCE) indicates that 36 percent thermal efficiency will be achieved out to the year 1983. Addition of combined cycle capability with its higher efficiency to existing generation plants within the SCAB may cause the overall average efficiency of thermal generation to increase slightly.

Beyond 1983 there may be some possibility to further upgrade the system with technological improvements to combined cycle systems. After 1985 it is expected that combined cycle systems will achieve 48 percent thermal efficiency, which is significantly better than the 40 percent presently postulated for combined cycle systems.[5] Thus an improvement of this degree could cause the SCE in-basin generation efficiency to rise significantly above the existing 36 percent level. Even further improvement may be possible if the magneto-hydrodynamic (MHD) topping cycle technology is successfully developed. MHD topped power plants may achieve efficiencies as high as 55 to 60 percent, but the availability of this technology is forecast for 1995 and beyond.[5] Consequently, our assumption of 36 percent efficiency throughout the forecast period must be regarded as conservative in regard to estimating electric car performance.

Transmission of electric energy may incur significant losses, depending on the distance of transmission as well as other transmission operations such as transforming voltage levels. These losses are difficult to allocate to specific end uses of electric energy; therefore we will use the SCE average loss rate of 9 percent.[15]

Battery discharge and recharge, as well as the conversion of electric energy to road mileage in electric cars, is a strong function of the detailed manner in which these operations are accomplished. In a companion study task concerned with electric car technology,[7] efficiencies for each of these operations are analyzed for typical expected charging and driving conditions. Based on a standard metropolitan driving cycle, near-term four-passenger electric cars with lead-acid batteries are expected to consume 0.79 KWH/mi, electric energy measured at the input to the battery charger. Similarly, intermediate-technology cars with nickel-zinc batteries are expected to consume 0.51 KWH/mi and advanced-technology electric cars with zinc-chlorine or lithium-sulfur batteries are expected to consume 0.41 and 0.45 KWH/mi, respectively. A smaller two-passenger car in all cases will consume less energy; however, the four-passenger configurations are better able to provide the accommodations of the conventional autos they most likely will replace. We would therefore not expect the two-passenger configuration to achieve as wide an acceptance among car buyers, and consequently we have chosen to base our comparisons on the four-passenger configurations.

The overall energy consumption rates for electric cars when recharged by in-basin thermal power plants are listed in Table 2.2 along with "break-even" gasoline mileages for conventional gasoline powered cars.

TABLE 2.2

AVERAGE PRIMARY ENERGY CONSUMPTION RATES ASSUMED FOR ELECTRIC CARS*
(Parentheses are break-even gasoline mileages including refinery energy)

Battery Technology		1980	1990	2000
Lead-Acid	(16.7)	8,250 Btu/mi		
Nickel-Zinc	(25.8)		5,330 Btu/mi	
Zinc-Chlorine	(32.2)		4,280 Btu/mi	4,280 Btu/mi
Lithium-Sulfur	(29.4)			4,710 Btu/mi

---

*Assumes 9 percent electric power transmission loss and 9,500 Btu/KWH conversion rate at the power plant.

2.1.4 Conversion of Non-Petroleum Energy Sources for Automotive Transportation

It was shown previously (in Task Report 5) that beginning sometime around 1990 coal-fired plants outside the basin would be utilized to an increasing degree to recharge electric cars during off-peak hours. Presently these plants are conventional Rankine cycle plants of relatively recent construction. By the year 2000 it is expected that in addition to coal and oil some nuclear power generation would be utilized during off-peak hours for recharging electric cars. Thus electric cars have the potential, even in the Los Angeles region, to shift some transportation to a non-petroleum source of primary energy consumption.

Much attention is being paid the possibilities of expanding our utilization of coal in order to decrease our dependence on imported oil. Although the baseline energy forecast for SCAB does not reflect a large usage of coal, the present interest in western U.S. coal reserves may presage an unexpected expansion in the use of this source for SCAB energy demand, and electric cars may become an important element in that demand.

However, other approaches to using coal as a primary source of automotive energy are also being investigated.[16] One very promising method involves the conversion of coal to synthetic crude ("Syncrude") from which motor gasoline is refined. This process is well suited to the subbituminous western coals, and furthermore the syncrude process involves the removal of unwanted sulfur.

A comparison of two alternative approaches to the use of coal as a primary source of automotive energy has been made. One alternative considers the path: coal-to-syncrude-to-gasoline-to-internal combustion powered car. The other considers the path: coal-to-low BTU gas-to-combined cycle power plant-to-electric car.[17] Both alternatives are clean processes insofar as sulfur removal is concerned. The comparison is made on the basis of overall thermal efficiency in converting coal energy to road miles. Large scale production of syncrude from coal is expected to be available beginning in 1982,[16] or about the same time that combined cycle, electric power plants utilizing low-BTU gas from coal are expected to be commercially feasible. This latter combination is presently being researched under the title of advanced power cycles (APC). Although the combined cycle portion of APC research is concentrated on a staged combination of Brayton and Rankine thermodynamic cycles, there is also the possibility that, later on, the magneto-hydrodynamic (MHD) topping cycle may become availble to replace the first stage or Brayton cycle.[5]

We have calculated the specific primary energy consumption--BTUs of coal per road mile of transportation--for each alternative path and the results are shown in Fig. 2.1.

The alternative converting coal to gasoline is depicted by three boxes, labeled as to the assumed gasoline mileages that could be obtained on the metropolitan driving cycle. The top of the box is the energy consumption rate if the total syncrude output is refined to gasoline, a process expected to be 0.65 efficient (coal-to-motor gasoline). If the refining of coal syncrude is split between motor gasoline and distillate fuels, overall efficiency is expected to be 0.70. The three boxes are cast in a time sequence generally reflecting our basic assumptions concerning improvement in future gasoline mileages obtained. However, there is no need to constrain the comparison in this way, and the reader is free to consider 30 mpg in 1982 if this is deemed a more appropriate comparison.

The coal-to-electric car energy consumption rates are somewhat more time constrained, in that the efficiencies of APC systems are forecast to increase as technology allows. The band depicting the expected range for APC-based systems reflects alternative forecasts of APC efficiencies.[5,17] We also show the effect of replacing the Brayton topping cycle of the APC with MHD topping which is assumed to produce even higher efficiences. The APC with MHD option is combined with each of three battery technologies which convert electricity to road miles utilizing the electric car configurations already presented. (The Li-S battery technology, which lies between the Ni-Zn and Zn-Cl in efficiency, was left out only to provide clarity in the figure). The circled point in 1974 is for reference only, showing the combination of a modern coal fired plant (Rankine cycle only at a heat rate of 9,000 BTU/KWH)[13] with a lead-acid battery, electric car.

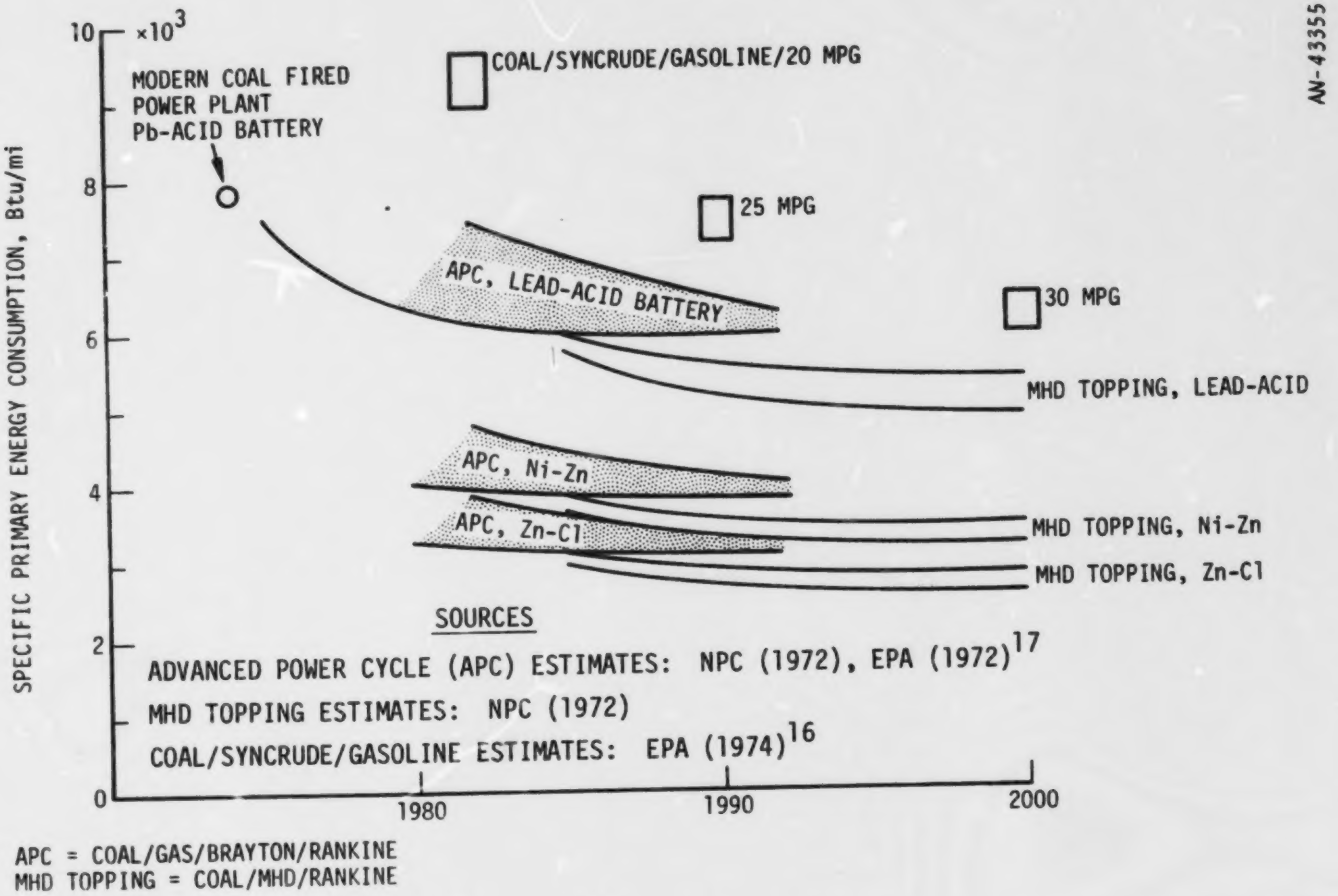

Figure 2.1. Comparison of Alternative Uses of Coal for Automotive Transportation

The coal syncrude conversion to motor gasoline is attractive because it promises to preserve the beneficial features and investments in our present mode of transportation. However, this is accomplished at some loss in overall thermal efficiency, primarily associated with the production of syncrude from coal. This is to be contrasted with the expected improvements in thermal electric generation efficiencies, which tends to enhance the possibilities of electric cars as the comparison in Fig. 2.1 clearly shows, especially with expected future battery technologies.

There are other constraining factors which can affect this comparison to a slight degree. First, no transport energy costs are included in the calculations. In the case of the coal syncrude process, the estimates are based on the syncrude plant located near the source of the coal. The refinery could be co-located in which case the transport of gasoline to the market is the major energy transportation cost. As previously mentioned, the estimates are based solely on conversion of western subbituminous coals which, for a national source of motor gasoline, may entail significant energy transportation costs. The APC alternative depends on conversion of coal to low-BTU gas which is uneconomical to transport over large distances. Thus the APC systems imply that electric power plants must also be somewhat near the source of coal. However, it is not known how well the coal gas conversion process is suited to other sources of coal (e.g., eastern anthracite and bituminous coals). Thus there may be inherently more flexibility in coal gas conversion to avoid energy transportation costs.

2.2 PRIMARY ENERGY CONSUMPTION

In the previous subsection the comparative energy consumption rates of electric and conventional autos have been analyzed and reduced to single values for energy consumption per mile representative of average trip-making conditions for SCAB. An analysis of likely levels of total future travel in SCAB[6] shows that the combination of expected auto populations and average miles driven per year for each car will result in the following totals for private automobile travel in SCAB:

1980	60.8 billion vehicle-miles
1990	72.0 billion vehicle-miles
2000	83.3 billion vehicle-miles

These are the values forecast without the introduction of electric cars. However, it is anticipated that successful application of future battery technology will lead to electric cars of sufficient range and performance not to affect trip-making behavior. Consequently, it is assumed that total vehicle-miles within SCAB will be the same with or without electric cars. Only in the case of the initial introduction of electric cars with near-term lead-acid technology is the range constraint likely to affect trip-making behvaior. However, even in this case it will be assumed that, although the lead-acid based electric cars will be driven fewer miles per year than the average auto, they will be second cars and routine adjustment of car-trip selections in multi-car households will compensate for the lowered electric-car mileage.

Based on the forecast SCAB automobile travel and the energy consumption rates for conventional autos (Table 2.1) and electric cars (Table 2.2),[*] the change in overall primary energy consumption as a function of electric car usage was calculated. Figure 2.2 presents the calculated

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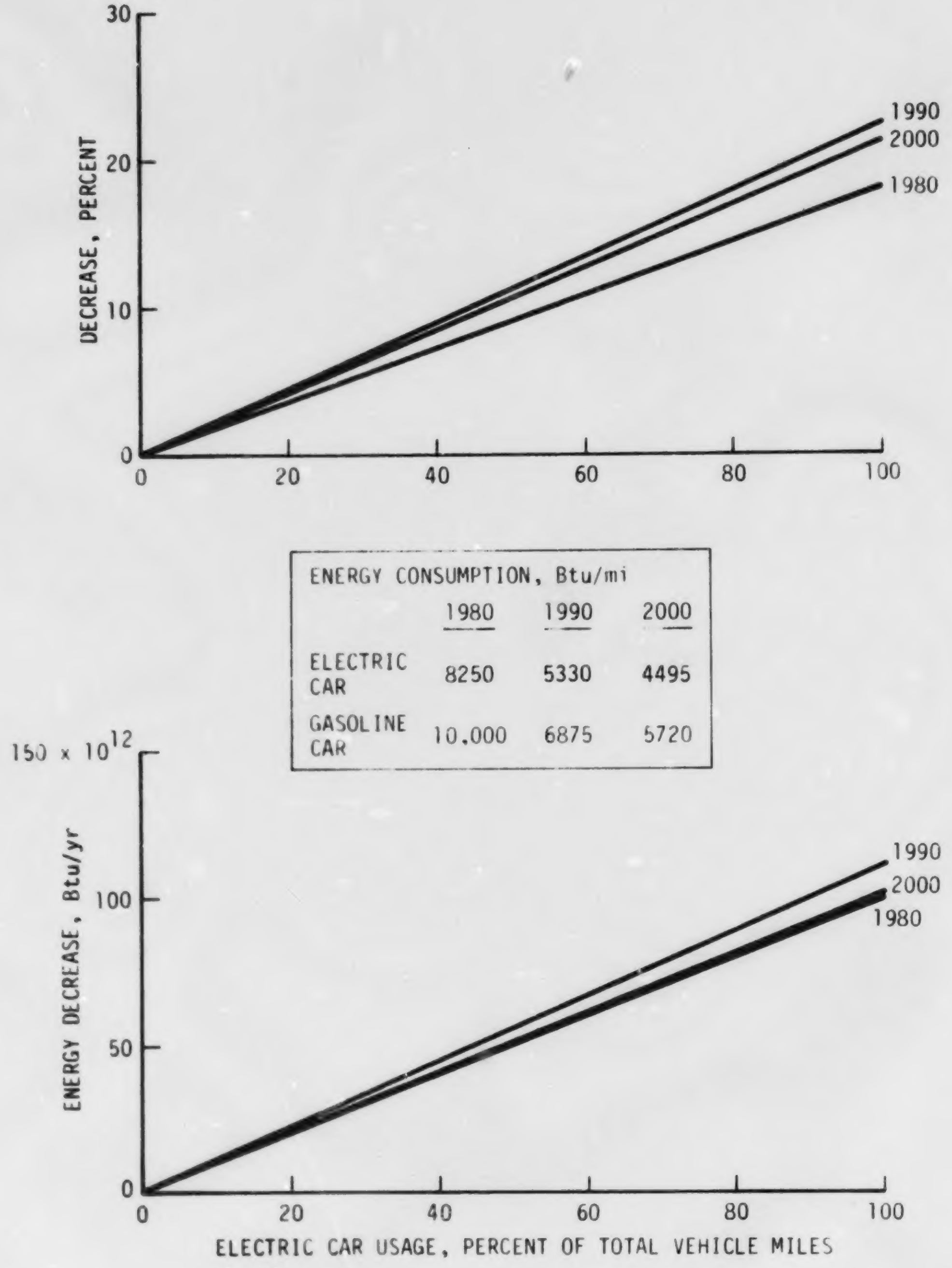
[*] For electric cars, the energy consumption rates used are based on the assumption that lead-acid technology is appropraite for 1980, nickel-zinc for 1990, and an average of zinc-chlorine and lithium-sulfur for 2000.



ENERGY CONSUMPTION, Btu/mi

	1980	1990	2000
ELECTRIC CAR	8250	5330	4495
GASOLINE CAR	10,000	6875	5720

Figure 2.2. **Decrease in Energy Consumption for Private Auto Travel Due to Electric Car Usage Relative to Average Gasoline Car**

changes, in terms of absolute energy and in terms of percentage of total energy consumed in auto travel, as a function of the percentage of total vehicle-miles in SCAB accounted for by electric cars. Curves are presented for each of the years 1980, 1990, and 2000 which show that, at high levels of electric car usage, and even with significant improvements in gasoline-auto efficiencies, electric cars can provide significant savings in total energy used for auto travel when compared to the average gasoline powered car.

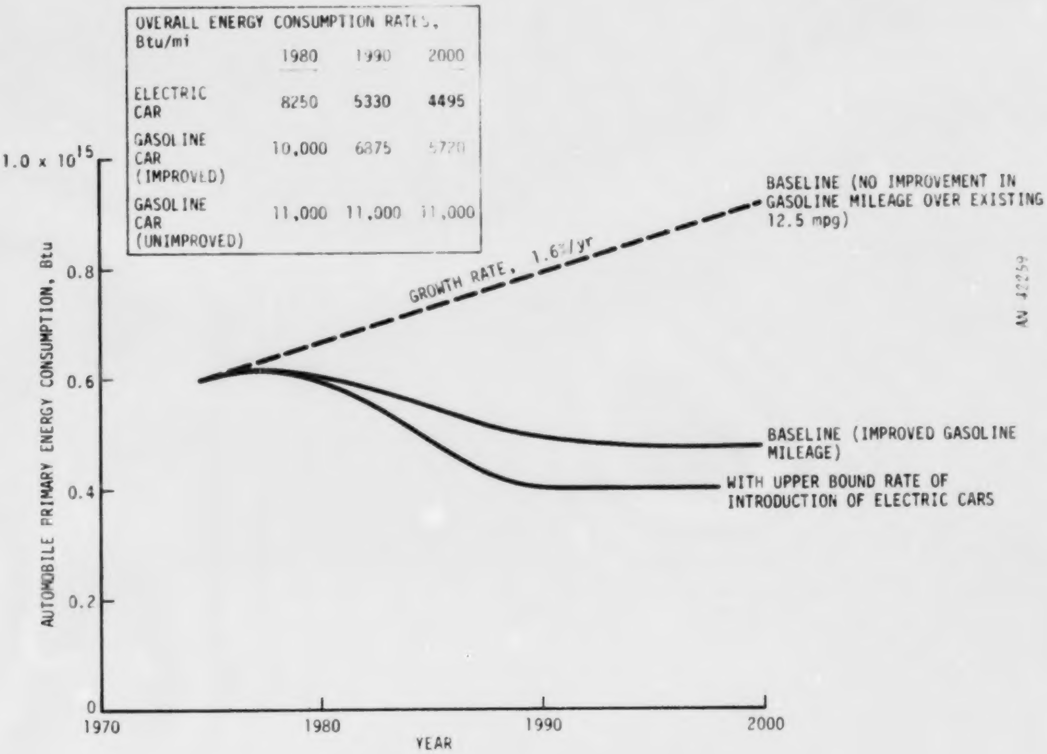
The parametric results of Fig. 2.2 were used to compute the energy impacts of several alternative scenarios, developed in Ref. 9, for electric car sales and use in the South Coast Air Basin. The range of possibilities is bounded on the upper end by a rate of electric car sales, which was taken as 80 percent of the new car sales in each year from 1978 through 2000. The lower bound is an estimate of the rate of sales based on the likely competitive position of electric cars in "free market" conditions. (Because the "free market" case results in such low electric car usages and consequently trivial or uninteresting impacts, an alternative rate at a constant 17 percent of market sales was postulated.) In between these bounds are two scenarios which assume progressively increasing market shares throughout the period of interest. The "high rate" of sales begins at 17 percent of the market and progressively increases to 75 percent by the year 2000. The "intermediate rate" is one-half the high rate. The resulting electric car percentages in the SCAB auto populations for each time period are listed in Table 2.3.

The impact of electric car sales and use on SCAB primary energy consumption for auto travel has been calculated and the results are presented in Fig. 2.3. Only the upper bound case for electric cars has been presented and compared with the energy consumption based on the assumed schedule for improved conventional automobile mileages. The primary energy consumption rates for other scenarios were not depicted as the differences between the baseline and upper bound case are not large.

TABLE 2.3

PROJECTED SCAB ELECTRIC CAR POPULATIONS FOR SEVERAL POSTULATED CAR SALES SCENARIOS

Scenario Rate of Sales	Percent Electric Cars in Auto Population		
	1980	1990	2000
Free Market	0.25	2.6	7.8
(Constant 17%)	4.8	15.5	17
Intermediate	2.4	15.5	30
High	4.8	31	60
Upper Bound	22.5	73	80



OVERALL ENERGY CONSUMPTION RATES, Btu/mi

	1980	1990	2000
ELECTRIC CAR	8250	5330	4495
GASOLINE CAR (IMPROVED)	10,000	6875	5720
GASOLINE CAR (UNIMPROVED)	11,000	11,000	11,000

Figure 2.3. Primary Energy Consumption for Total Auto Travel

It is significant to note that auto travel energy consumption without electrics, and with no improvements in mileage, is projected to grow at an annual rate of 1.6 percent per year as indicated by the dashed line in Fig. 2.2.[5] This is in contrast to the forecast made by Stanford Research Institute for energy consumption in the transportation sector of Southern California, which they projected to grow at 3.2 percent per year.[11]

The curve depicting the baseline condition with improved gasoline mileage shows a large impact on automotive energy consumption from lowering gasoline consumption. It may be argued that these are only goals to be achieved and hence are quite likely to overestimate the degree of improvement that may occur. Even so, the electric cars have the potential to further improve somewhat on this situation. In this respect there is an interesting observation that can be made concerning the conditions which are likely to create an incentive to achieve improved gasoline mileages. If in the indefinite future there is a continuing high-level concern with the efficiency with which we consume energy in travel activities, the introduction of a relatively efficient electric car in competition with conventional autos may provide the necessary incentive. Conversely, without efficient competing alternatives, the rate at which we approach our goals is likely to be much slower.

On the other hand, if the prospects for future electric generating plant efficiencies of 50 percent and higher are realized, then the advantages of electric cars over even the postulated more efficient year-2000 conventional autos will be further enhanced, and overall energy consumption in transportation would be lower than that indicated in Fig. 2.3 for a given mix of electric and conventional cars. This association of electric car overall energy consumption rates with the higher efficiencies achieved with combined cycle power plants (assumed to use fuel oil) is correct, providing that future utility policy is to provide base loads from nuclear and out-of-basin coal fired plants.

It is conceivable that future economic conditions in combination with significant changes in the hourly demand profiles may require a reordering of power plant generation priorities, although we consider it unlikely as long as some oil (the most costly fuel source for the indefinite future) is required.

2.3 GASOLINE CONSUMPTION

The same basic assumptions used in the calculation of primary energy consumption were used as the basis for calculating the impact of electric cars on SCAB gasoline consumption. The results of these calculations are presented in Fig. 2.4, which shows that for all but the "free market rate" scenario, electric car use would have a significant impact on gasoline sales in the basin. At the upper bound rate of electric car sales, corresponding use in the year 2000 will require about one-fifth the existing gasoline sales to fuel the remaining conventional autos.

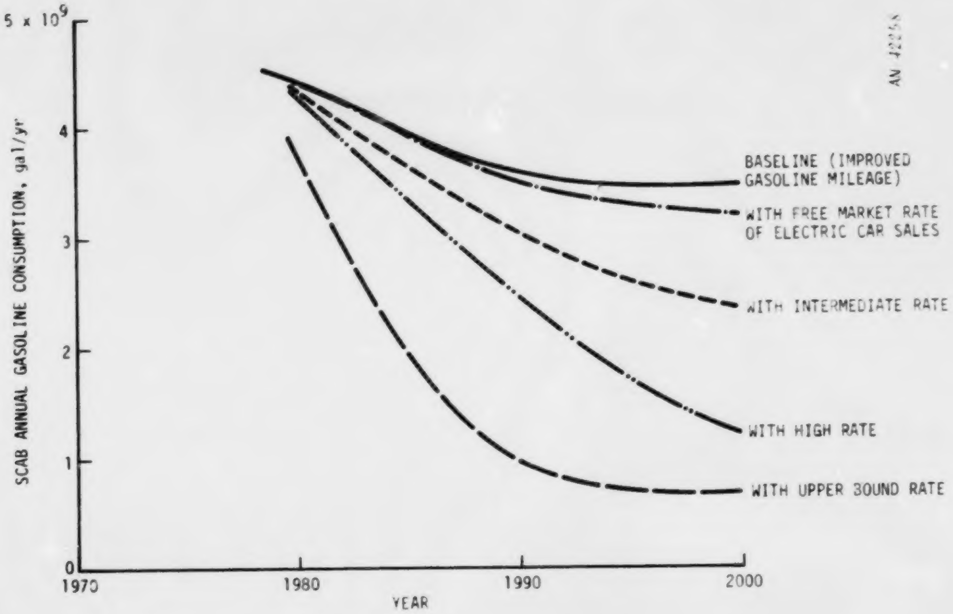


Figure 2.4. Private Auto Gasoline Consumption

2.4 POWER PLANT GENERATION

It is assumed that recharging of electric cars will routinely make use of the available generating capacity during off-peak hours. Off-peak recharging can virtually be guaranteed by designing special features in home recharger equipment. For example, it is quite feasible to design special sensor circuits in the recharger that can be activated by modulating the power delivery with a unique signal. The modulated signal would be sent from the generating station to a sector (or sectors) of the service area whenever the total load approached the peak capacity of the station. Receipt of the signal at the rechargers in a selected sector would cause these rechargers to shut off.

For each electric car scenario, the daily vehicle-miles driven by electric cars were calculated from annual totals, assuming equal distribution over 365 days. Allowing for a 9 percent transmission loss, daily vehicle-miles were converted to daily requirements for recharge energy for both existing and advanced battery technologies (0.79 KWH/mi and 0.45 KWH/mi, respectively). Also, the available off-peak energy as a function of peak demand was calculated for the years 1980, 1990, and 2000 based on the forecasts presented in Ref. 5 for both peak day and average weekday conditions. Figure 2.5 shows the assumed hourly profiles of electrical demand for two levels of SCAB electric car usage (shown as a percentage) for each time period based on peak day conditions.[*] The shaded regions in the figures indicate the portions of total generation that are used to recharge electric cars in the normal off-peak period.

The electrical energy generation available for electric car recharge during the off-peak period as a function of the level of off-peak demand

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[*] The particular levels of electric car usage shown in Fig. 2.5 were chosen earlier to bound the parametric study of air pollution undertaken in a companion study task.

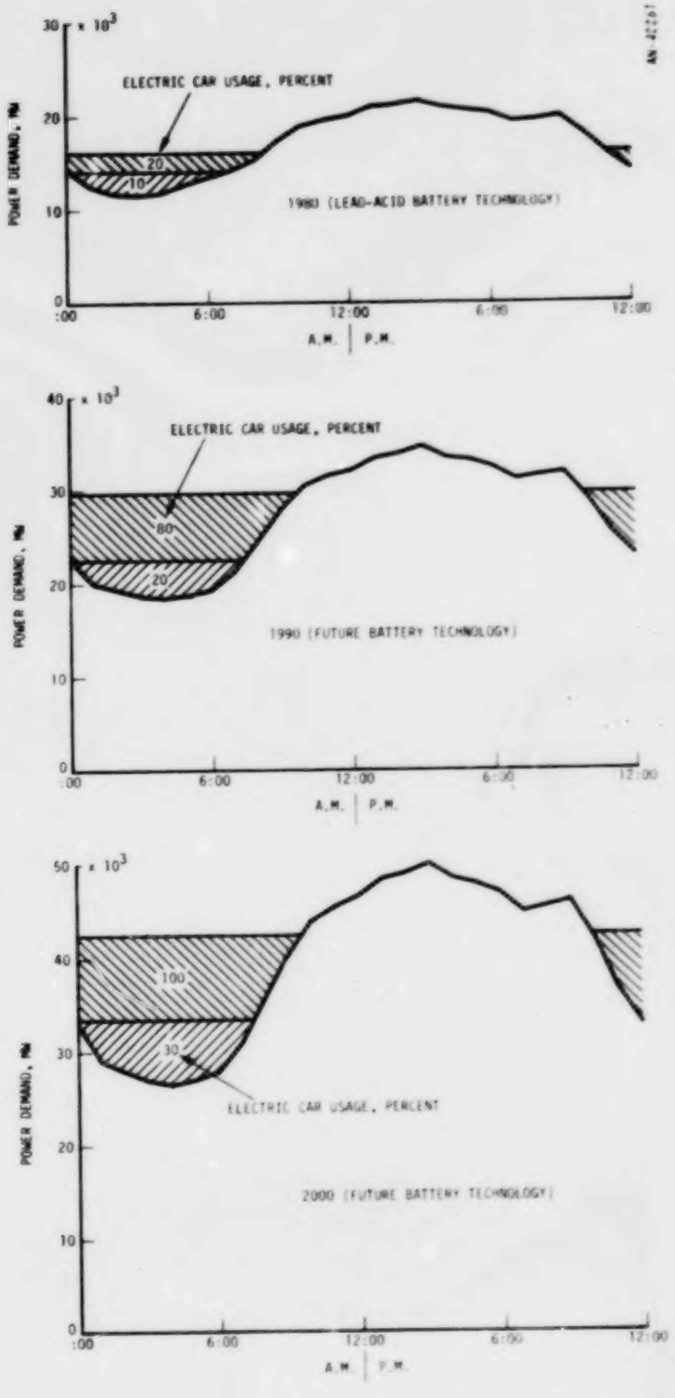
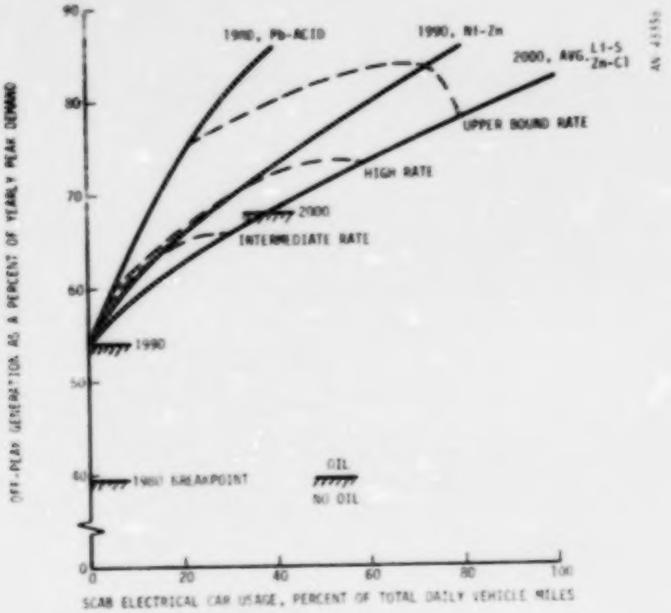


Figure 2.5. Electric Power Demand Profiles

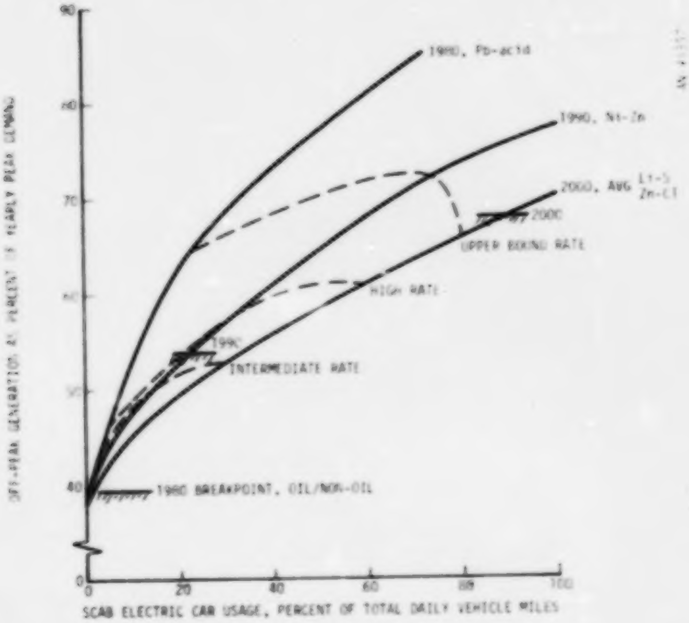
was calculated for each time period for both peak day and average week day conditions. These amounts of recharge energy were then converted to electric car usage, assuming appropriate car efficiencies for each time period. The results of these calculations are depicted in Fig. 2.6, where off-peak demand is shown on the ordinate in terms of the percent of peak capacity for each of the three time periods and SCAB electric car usage is presented as the percent of all SCAB vehicle miles driven by electrics. Cross-plotted on Fig. 2.6 are the requirements to meet electric car usage for each of three scenarios governing the rate of electric car introduction to the general auto population (the low usage scenarios show minor impact on off-peak demand and are not depicted in the figure).

It is expected that the off-peak demand shown for the years 1980, 1990, and 2000 would require the excess generation to occur typically between 10 p.m. and 9 a.m., as shown in Fig. 2.5 (1980 off-peak demand will probably be between 11 p.m. and 8 a.m.). Undoubtedly, some of the recharging requirements will be met outside this time interval, with some occurring during the peak hour. Assuming that 10 percent of the recharge requirement might be uniformly spread over the complementary period (9 a.m. to 10 p.m.), we estimate that peak demands will be increased by less than 2 percent over what is otherwise forecast.

SCAB power plants need only operate at 84 percent of peak demand during the off-peak period on peak days in the year 1990 to meet the requirements for the advanced battery systems at the upper bound rate of electric car population buildup. Lead-acid battery systems at these high utilization rates in the years 1990 through 2000 would overtax the off-peak capacity of the basin's power plants on peak days. The situation for average weekday conditions is quite different. At the upper bound rate of electric car population buildup, off-peak demand for electric car recharge maximizes at 72.5 percent of the yearly peak demand. And based on these average weekday conditions, substantial usage of electric cars based on lead-acid batteries could be supported (72 percent usage



a) Peak Day Conditions



b) Average Weekday Conditions

Figure 2.6. Off-Peak Power Generation for Different Battery Technologies and Introduction Scenarios

at 85 percent of yearly peak demand in 1980). However, such usage levels could not be accommodated on peak-days.

We have also indicated (see curves, Fig. 2.6) the levels--in percent of yearly peak demand--for each time period above which the primary source of energy for electric generation would be fuel oil. Below these levels coal, nuclear and hydroelectric sources would be utilized. In general additional off-peak generation during peak day conditions would be met by fuel oil for the 1980 and 1990 time periods, but by 2000 substantial amounts of off-peak generation from non-oil sources could be utilized. For average weekday conditions oil would be used exclusively for additional off-peak generation only during the 1980 time period. By 1990 a 22 percent electric car usage could be supported with non-oil sources of electric generation, reaching almost a 90 percent usage level in 2000 before oil sources would be required.

2.5 PETROLEUM SAVINGS

Large scale usage of electric cars may produce significant reductions in the amount of petroleum used as a source of primary energy. First because they may be slightly more efficient than the average gasoline car they can effect savings in petroleum use. Second, because power plants under average weekday conditions in the future will be able to utilize non-petroleum sources to make recharge energy available for electric cars, much of the daily vehicle mileage displaced from gasoline autos by electric cars will produce proportionate savings in petroleum required. These two effects have been incorporated in a calculation of the average petroleum saved as a function of electric car usage and the results are presented in Fig. 2.7. The savings, shown as the ordinate, are expressed in percent of the amount that would have been otherwise used for the baseline forecast with all gasoline powered cars and with the improved schedule of average gasoline mileages. Electric car recharge requirements and the supply of electric recharge energy are based on the generation capabilities for average weekday conditions as shown in Fig. 2.6.

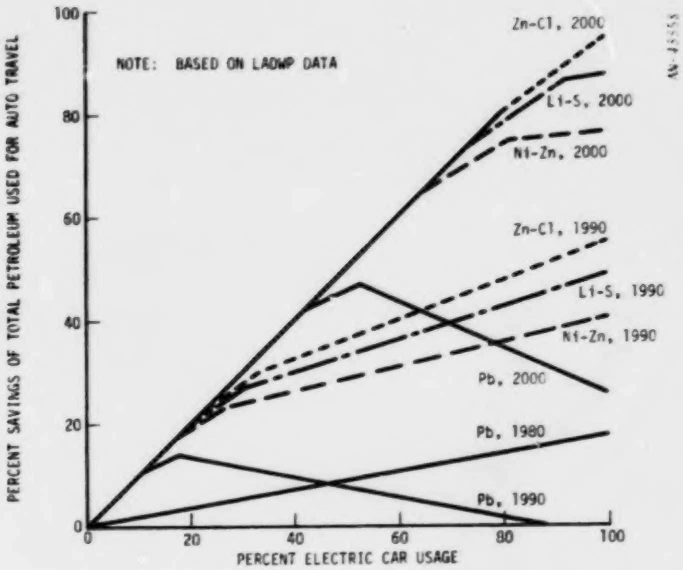


Figure 2.7. Petroleum Savings As a Function of Electric Car Usage (SCAB)

However, each battery technology has been kept separate in these calculations as indicated in the figure.

In general, for a given year and battery technology, savings are directly proportional to usage until a point is reached where in the lowest demand period in the year oil must be used during off-peak to recharge electric cars. At higher average usage rates there are a greater fraction of days on which off-peak demands must be met by oil sources. Finally with still higher usage levels the peak day condition is reached where all additional off-peak demands draw from oil sources that would have been used to power the gasoline cars displaced by electrics. At this point the savings are proportional to the differences in overall conversion efficiencies (Btu/mi), which for the case of lead-acid electric cars in 1990 and beyond favor gasoline cars (down sloping curve), and in the cases of electric cars with future battery technologies favor electrics over gasoline cars. In every case the curves represent an upper bound which are quite close to curves that would be developed from actual distribution functions of hourly demands instead of representative low, average, and peak demand characterizations. Incorporation of an actual distribution function would produce a smooth curve, lying slightly under the bounding line segments, but tangent to the first and third segments.

Figure 2.7 clearly shows that for 1990 and 2000 significant savings in petroleum are potentially possible with conversion to electric cars with future battery technologies. Only small savings are possible with lead-acid based cars in 1980 and in 1990 at low usage rates.

3 RESOURCE IMPACTS

The most significant demands on resources associated with the production of electric cars have already been identified.[8,10] In general the materials required for several of the proposed battery systems pose the most serious resource impacts. These include lead, antimony, nickel, zinc, graphite, titanium, and lithium. Also, motors and other electrical gear may place significant demands on copper supplies.

The impacts of SCAB electric car requirements for these materials on traditional and forecast supply and demand relationships for the entire United States have been quantified as a function of the level of electric car use in terms of the percent of total SCAB vehicle-miles driven by electrics. The inventories of materials for each battery technology and alternative electric-car configuration are presented in Ref. 7 and form the bases for the impact assessments that follow. However, consistent with the energy impact assessments presented in the previous section, only the four-passenger configurations in Ref. 7 have been included for study. Basic information on supply and demand relationships has been drawn largely from the 1970 edition of the Bureau of Mines compilations[18] of mineral resource data.

The annual material requirement for a given battery component (plate, terminal, electrolyte, etc.) or other unique electric car component depends on several factors. First, each new car sold must be supplied with the component. Second, depending on the life of the component and the past history of car sales, components in older cars may be frequently scrapped; total component sales must take this factor into account.

For materials that are scarce, there will be strong incentives to salvage them. The percentage of scrap recycled as secondary materials production depends strongly on price incentives, reflecting primarily the scarcity. At present, a high percentage of battery lead is recycled.

1969 figures published by the Battery Council International (BCI)[19] show that 520,913 tons of battery lead were reclaimed while demand for battery lead was 582,546 tons. Thus lead reclaimed was approximately 90 percent of lead demanded. If these values were to represent steady-state conditions it would be reasonable to assume a 90 percent effective recycle reate. However, a BCI spokesman indicated that 85 percent was probably a more representative value. No other materials, with the exception of antimony,[*] have demonstrated the rate of recycle that lead has. However, the employment of heretofore new materials in battery systems on a wide scale may provide the basis for the development of similar recycle industries as well as stimulate existing recycle operations.

For example, there is the prospect, with relatively high levels of electric car usage, for development of retail battery service centers, where electric car batteries are exchanged routinely. The fact that an electric car battery has a salvage value of say one or two hundred dollars, rather than the two or three dollars for today's accessory battery, means that few electric car batteries will ever be lost in the shuffle. Also such battery centers will ease the collection problem by providing conspicuous collection and exchange points, thereby aiding in the collection of all other storage batteries. Furthermore, because electric car batteries are expensive but necessarily replaceable, there may be incentive towards designing standardized as well as reusable battery cases. At present, the cases from scrapped batteries pose significant solid waste problems, especially since environmental sanctions prohibit burning them in many places. Used electrolyte from scrapped batteries also poses a waste disposal problem, but it is difficult to speculate what opportunities may be afforded for mitigating this problem.

The requirements for scarce or critical materials to support various levels of electric car usage in SCAB have been related parametrically to the amount of material supplied from recycle, and to average battery life. The material requirement is calculated in terms of the annual amount of new material required. Recycled material is expressed as the annual amount (in percent) of the total material requirement supplied from reclaimed sources. This percentage should not be confused with a strict definition of recycle efficiency, which defines the fraction reclaimed of that potentially available. For example, in cases where electric car populations are rapidly building after their initial introduction, a recycle efficiency of say 85 percent may provide only 60 percent of the total material requirement. Consequently, simple parametric representations of resource impacts may tend to underestimate the significance of the effect on resources due to the rate of buildup of the electric car population. Figures 3.1 and 3.2 illustrate these effects by showing the demand for new batteries, and the available recycled batteries, for the range of scenarios governing the sales and use of electric cars within SCAB developed in Ref. 9 and previously summarized in Sec. 2.2. Figures 3.1 and 3.2 depict, as examples only, the cases for two-year battery life and an 85 percent recycle efficiency (defined as the percentage recycled of those potentially available for recycle).

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[*] Most of the recycled antimony is in the form of antimonial lead, used primarily in storage batteries.

In general, the results of the parametric impact analysis on materials requirements include two ranges of battery life, two years and three years, and three levels of material supplied from reclaimed sources, 85, 90, and 95 percent. The choice of battery lifetimes of two and three years are based primarily on experience and expectations with lead-acid batteries. Consequently, these choices may not be representative of future batteries where lifetimes of five or more years may be feasible with, for example, nickel-zinc batteries. In cases where future technology may produce longer battery lifetimes, the parametric results that follow will underestimate the amount of materials supplied from reclaimed sources and overestimate the requirement for new materials. In a like manner, the range in the fraction of material supplied from reclaimed sources may not adequately span the possibilities with some of the future batteries. However,

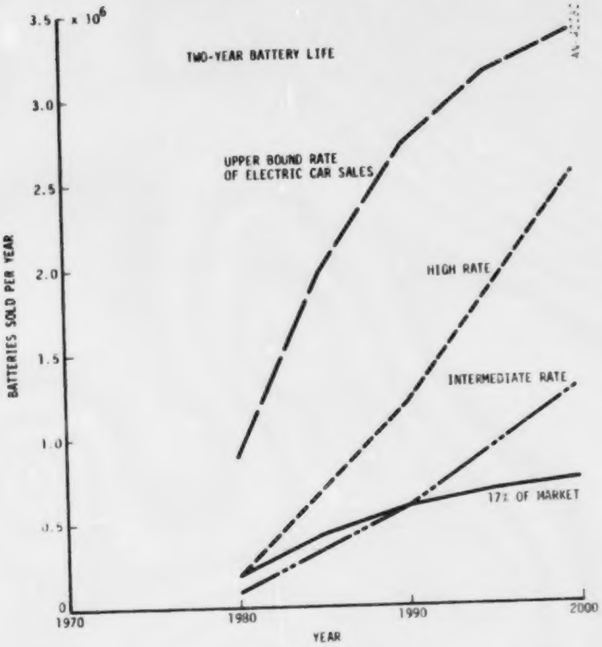

Figure 3.1. Annual Battery Sales in SCAB

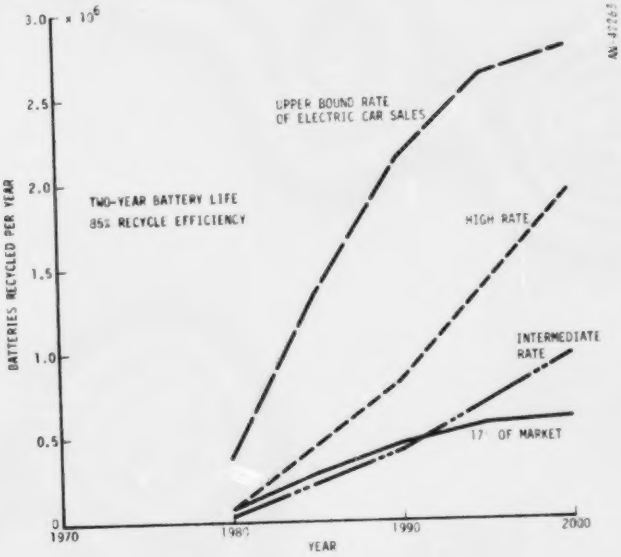

Figure 3.2. Annual Battery Recycle in SCAB

it is extremely difficult to predict such possibilities. The low end of the range of recycle, 85 percent, is representative of present experience with lead-acid batteries. It is expected that the dollar value of a single electric car battery system should cause a significant improvement in this situation which we allow for by the higher recycle levels of 90 percent and 95 percent. However, in some cases where a single battery may contain raw materials approaching $1,000 in value, such as may be the case with nickel-zinc, it is difficult to imagine any significant losses from the used battery inventory. In such cases the parametric results would produce conservative estimates of the new material required.

To provide further insight into the effect of the rate of buildup of electric car population on resource requirements, additional curves for each mineral are presented, showing the electric car requirement for new materials as a function of time over the period 1980 to 2000 for each of several selected scenarios.[9]

In the analyses of resource impacts that follow, consideration is given primarily to existing lead-acid battery technology and to foreseeable future battery technologies (nickel-zinc, zinc-chlorine, and lithium-sulfur cells). Provision of lead-acid batteries for electric cars on any significant scale for SCAB may pose problems in the supply of lead and antimony. Large-scale use of nickel-zinc batteries within SCAB may cause significant perturbations in the national supplies of these two metals; other incidental battery materials will be of minor consequence. Zinc-chlorine batteries may also perturb zinc supplies, but to a lesser degree than nickel-zinc batteries at the same scale of employment. Zinc-chlorine batteries also require potentially significant amounts of titanium, but there should be no difficulty in providing chlorine. Lithium-sulfur batteries, when provided for large numbers of electric cars, will impact supplies of lithium and graphite most significantly, while sulfur supplies should be virtually unperturbed.

3.1 SCAB ELECTRIC CAR RESOURCE IMPACTS

3.1.1 Lead

Figures 3.3a and 3.3b show the annual requirements for primary production (new material) of lead as a function of electric car usage in SCAB. Three sets of curves are shown representing percentages of 85, 90, and 95 percent of material supplied from reclaimed resources. Each set is further broken down to representations for each time period of interest, 1980, 1990, and 2000. Also shown is the Bureau of Mines (BOM) forecast[18] for US primary lead demand to the year 2000, and the BOM estimate of 354,000 tons for the 1968 US production of primary lead from domestic mine sources.* Total US primary lead demand in 1968 was 898,000 tons, the difference being made up largely of imports. Because a high level of battery recycling takes place, battery demand is not the most significant item in total primary demand. Thus Fig. 3.3 shows that electric car usages greater than 20 percent or 30 percent in the SCAB begin to require appreciably greater proportions of primary lead for batteries than in the past, which may significantly perturb forecasts of primary lead demand. However, higher utilizations of electric cars are not generally consistent with the constraints (primarily limited range) imposed by lead-acid battery technology. Consequently, a reasonable level of utilization of electric cars in SCAB should not unduly disturb future lead supply and demand relationships. Nonetheless, since total US lead supply depends heavily on foreign sources, there may be some concern regarding the impact of any additional demands.

To demonstrate the effect of the rate of buildup of the electric car population, Fig. 3.4 depicts the annual requirement for primary lead over time for each of three scenarios governing the introduction of electric cars. The case labeled "upper bound rate of sales" places

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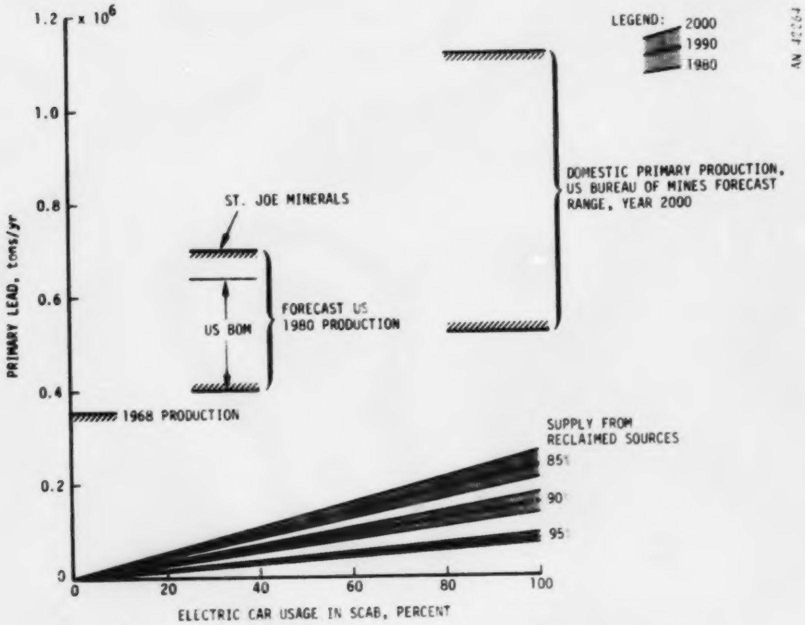
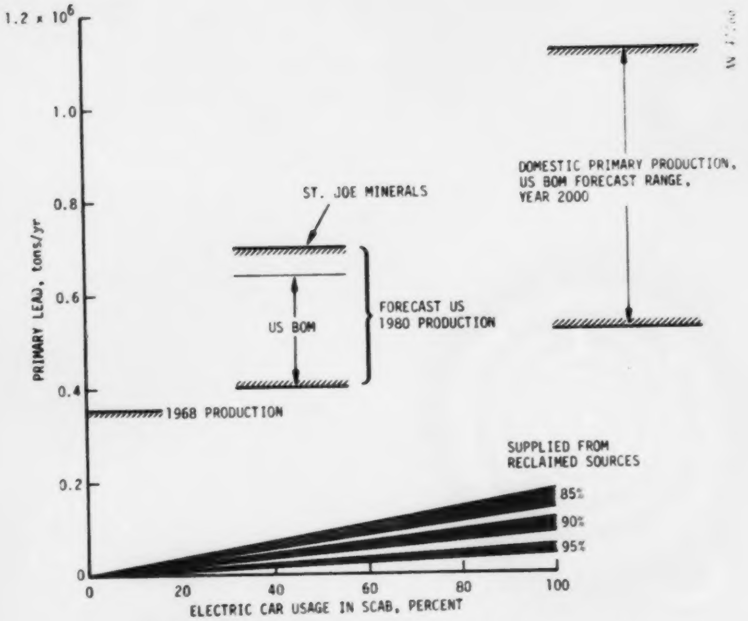
*Mineral production is variously quoted in short, long, and metric tons. In this paper, short tons (2000 pounds) are used throughout.



(a) Two-Year Battery Life



(b) Three-Year Battery Life

Figure 3.3. Lead Requirement as Function of Usage in SCAB

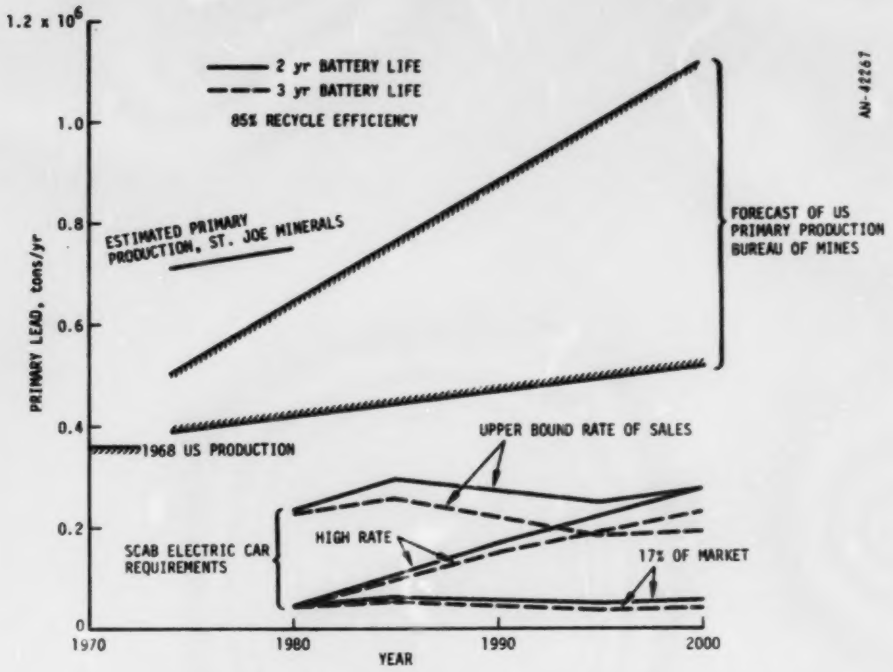


Figure 3.4. Lead Requirements as Function of Time

significant demands on primary lead supplies from the start until about 1985, when the electric car inventory is sufficiently large that reclaimed lead becomes a significant source of supply. The "high rate" case builds electric car inventories more slowly, and consequently primary lead demand builds more slowly. However, by the year 2000 the "high rate" case begins to surpass in primary lead requirement the "maximum rate" case, even though its electric car population is less.

Another factor in the lead supply and demand relationship deserves mention. The single most important consumptive use of lead is for anti-knock gasoline additives. The BOM forecast, based essentially on 1968 and earlier data, has allowed for a significant expansion of this use for lead; however, more recent appraisals,[20] consistent with current environmental concerns, project a significant decline in this use of lead.

It is of interest to examine what effects the combination of electric cars with the elimination of lead additives might have on forecasts of lead supply and demand. Table 3.1 has been prepared to summarize lead demand forecasts with and without electric cars.

The first part of Table 3.1 shows the expectations without electric cars. The data for the years 1968 and 2000 are from the BOM, while 1974 and 1980 data are taken from analyses by St. Joe Minerals.[20] The year-2000 forecast of 3,650,000 tons total demand assumes 900,000 tons used for lead additives. We assume that the alternative zero level for lead additives in 2000 reflects an increasing environmental concern. Recent data reported by the Battery Council International (BCI) show lead demands for additives down in 1971 from the levels in 1969 and 1970. Furthermore, as shown in Table 3.1, St. Joe Minerals expects lead demand for additives to be down by 68 percent in 1980, consistent with existing EPA regulations to reduce lead in gasoline from existing levels of 2.2 g/gal to 0.5 g/gal by 1979.

The second half of Table 3.1 shows the effect of SCAB electric car requirements on lead demand forecasts, for both storage battery and total demands. We assume that the alternative low forecasts for lead additives are appropriate in estimating total demand. Comparison of the two cases--with and without electric cars--shows that the assumptions governing lead additives are crucial to the overall forecasts of lead demand. The year-2000 demand without electrics but with expanded use of lead additives is within 15 percent of total demand with electrics in the SCAB and no additives for the maximum rate of electric car sales.

Consideration of the fact that battery lead is recyclable, while gasoline lead is not, makes this comparison more significant. Table 3.2 summarizes the effect on lead supply for the two corresponding cases, with and without electric cars. The calculations assume that 85 percent of storage battery lead will be recycled as secondary production, leaving all other lead uses to be made up by primary production, imports,

TABLE 3.1

RELATIONSHIP OF SCAB ELECTRIC CAR REQUIREMENTS TO US LEAD DEMAND

	Lead Demand, Thousands of Tons			
	1968[*]	1974[**]	1980[**]	2000[*]
No Electrics				
Total US Demand	1449	1515	1465 1655	2740 3640
Storage Batteries	500	750	930	1750
Lead Additives to Gasoline	262	260	90 280	0 900
Other	690	505	445	990
With Electrics in SCAB				
Storage Battery Demand (2-year life)				
Upper Bound Rate of Sales			1349	3147
High Rate			1020	2878
17% of Market			1020	2053
Total Demand[†]				
Upper Bound Rate of Sales			1884	4137
High Rate			1575	3868
17% of Market			1555	3043

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[*] Bureau of Mines, base forecast. Range of total demand in year 2000 is 2,520-to-4,140-thousand tons.

[**] St. Joe Minerals Corp.

[†] With electrics, it is assumed that low projections of lead additives are appropriate.

TABLE 3.2

RELATIONSHIP OF SCAB ELECTRIC CAR REQUIREMENTS TO US LEAD SUPPLY

	Lead Supply, Thousands of Tons			
	1968*	1974**	1980**	2000*
No Electrics				
Total US Supply	1636	1670	1620	3640
Primary Production (Including US Refining of Imported Ores)	487	710	750	520 1120
Imports	338	150	120	
Stockpile	260	185	50	
Subtotal	1085	1045	920	(2140)†
Secondary Production	551	625	700	(1500)†
With Electrics in SCAB (85% Recycling, 2-year Life for Batteries)				
Secondary Production				
Upper Bound Rate of Sales			856	2525
High Rate			733	2290
17% of Market			733	1717
Remaining to be Supplied†† by Primary Production, Imports, and Stockpile (to be Compared with Subtotals Above)				
Upper Bound Rate			1028	1612
High Rate			842	1578
17% of Market			822	1326

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*Bureau of Mines, base forecast.

**St. Joe Minerals Corp.

†Assumes 85% of storage battery demand for secondary production, leaving 2140 to be supplied from primary production, imports, and stockpile.

††Assumes total demand forecast with electrics, Table 3.1.

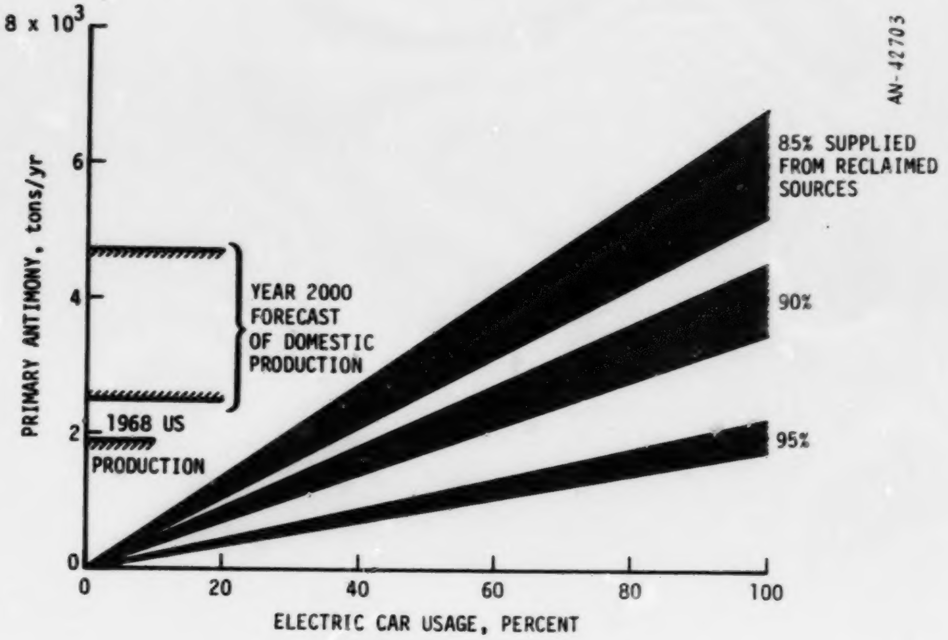
and stockpile. Comparison of required primary lead supplies (including imports) with and without electric cars shows that requirements for the introduction of lead-acid batteries on a large scale in the SCAB are within very reasonable bounds and generally well below the BOM year-2000 forecast. However, this situation further underscores the importance of the assumptions governing the lead additive forecasts in the BOM estimates.

3.1.2 Antimony

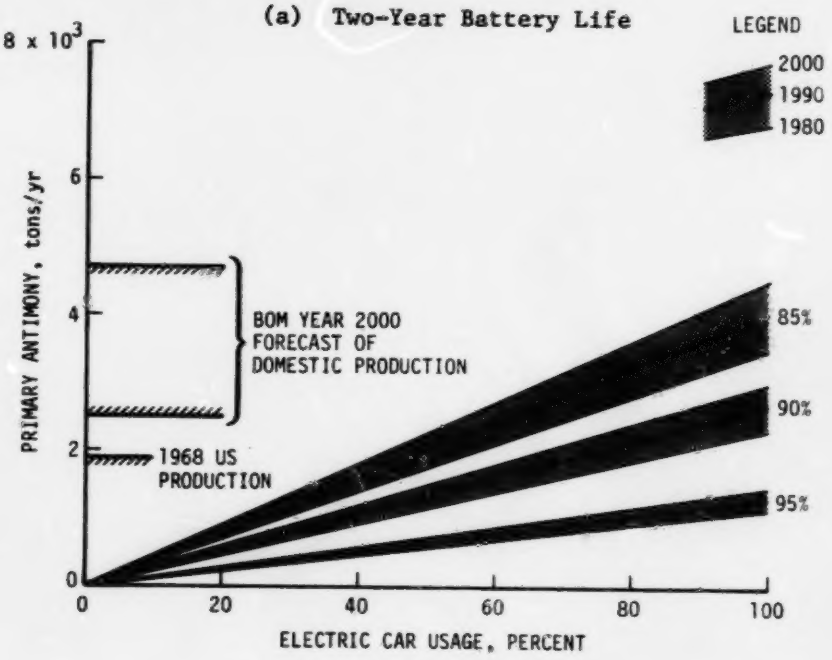
Present lead-acid batteries have about 2.5 percent of antimony alloyed with the lead to improve battery performance. Storage batteries accounted for 48 percent of total US antimony demand in 1968; consequently antimony, like lead, has a high recycle rate. Figure 3.5 shows the SCAB electric car requirements for primary antimony as a function of electric car usage. Figure 3.6 presents electric car requirements for primary antimony as a function of time over the period 1980 to 2000 for several electric car sales scenarios. Also shown for reference is the US 1968 demand and domestic production for primary antimony, which indicates that under present conditions the US is heavily dependent on foreign sources of antimony.

Except for this greater reliance on foreign sources, the expectations for future antimony demands parallel closely those for lead. Antimony reserves in the US are small, estimated in 1968 by the BOM to be only 110,000 short tons. World reserves appear adequate for electric car use in SCAB, but half of them are in China. The greatest US stock of antimony is contained in antimonial lead in use, which is highly recyclable. This stock of antimony was estimated in 1968 to be 181,000 tons, which at a high recycle rate constitutes the most significant US reserve.

A technological change is taking place which may ultimately eliminate lead-antimony alloys in battery grids. Other, more plentiful



(a) Two-Year Battery Life



(b) Three-Year Battery Life

Figure 3.5. Antimony Requirement as Function of Usage

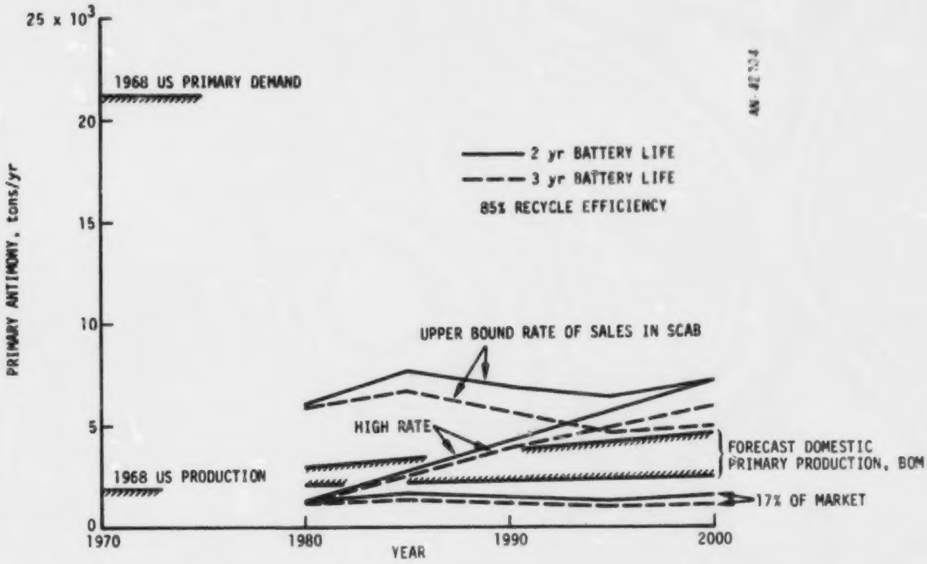


Figure 3.6. Antimony Requirements as Function of Time

materials, such as calcium, may be used in place of antimony to provide maintenance-free batteries. While promising to alleviate US dependence on foreign sources for antimony, the new battery requirements may pose short-term technological and eocnomic problems for the lead recycling industry.

3.1.3 Nickel

Nickel-zinc batteries may provide the earliest available replacement for lead-acid batteries, leading to significant improvements in overall electric car performance. The nickel-zinc battery envisioned for a four-passenger electric car will weigh just over 1,000 pounds (total battery system weight), of which 362 pounds are nickel metal and 328 pounds are zinc oxide (representing 263 pounds of zinc metal). For this battery configuration it appears that nickel supplies will be the most critical. The annual requirement for primary nickel has been calculated as a function of the percent of electric car usage in SCAB, and the results are presented in Fig. 3.7. Three sets of curves are shown, representing three different levels of the amount of nickel that may be supplied by recycling old batteries. For each level, the curve set breaks out the relationship for the years 1980, 1990, and 2000. Also shown are the 1968 levels of US primary production and demand, which indicate that we rely on external sources almost completely. The level of demand in the year 2000 forecast by the Bureau of Mines (BOM) is also shown for reference. As Fig. 3.7 indicates, the forecast of US nickel demand will allow for high levels of electric car usage in SCAB, especially at high recycle rates. However, high levels of electric car use nationwide (see Sec. 3.3) would very likely cause the BOM forecasts to be exceeded, even for high recycle rates.

Figure 3.8 presents the requirement to supply primary nickel as a function of the rate of buildup in electric car populations over the period of interest, assuming of course that the nickel-zinc batteries could be commerically available in 1980. The annual requirement is shown for three scenarios governing the rate of sales, assuming 85 percent recycle efficiency of the battery nickel and two values for average battery life. Also shown is the BOM forecast for primary demand and production. With the possible exception of the curve representing the "upper bound rate of sales," the figure shows that the buildup of electric car populations within SCAB can be achieved without an undue perturbation of expected future demands for nickel in the US.

Metallic nickel is relatively expensive, but world supplies are deemed sufficient to provide for the worldwide forecast demands without requiring too much of a price increase. Despite its high price, less than 20 percent of total nickel supply is from secondary sources. Use of scrap metal is most easily facilitated when the intended second use is the same as first. At present this causes difficulty in using old scrap, because it must be carefully sorted. In the case of nickel-zinc batteries, where the nickel is not alloyed and can be promptly reclaimed,

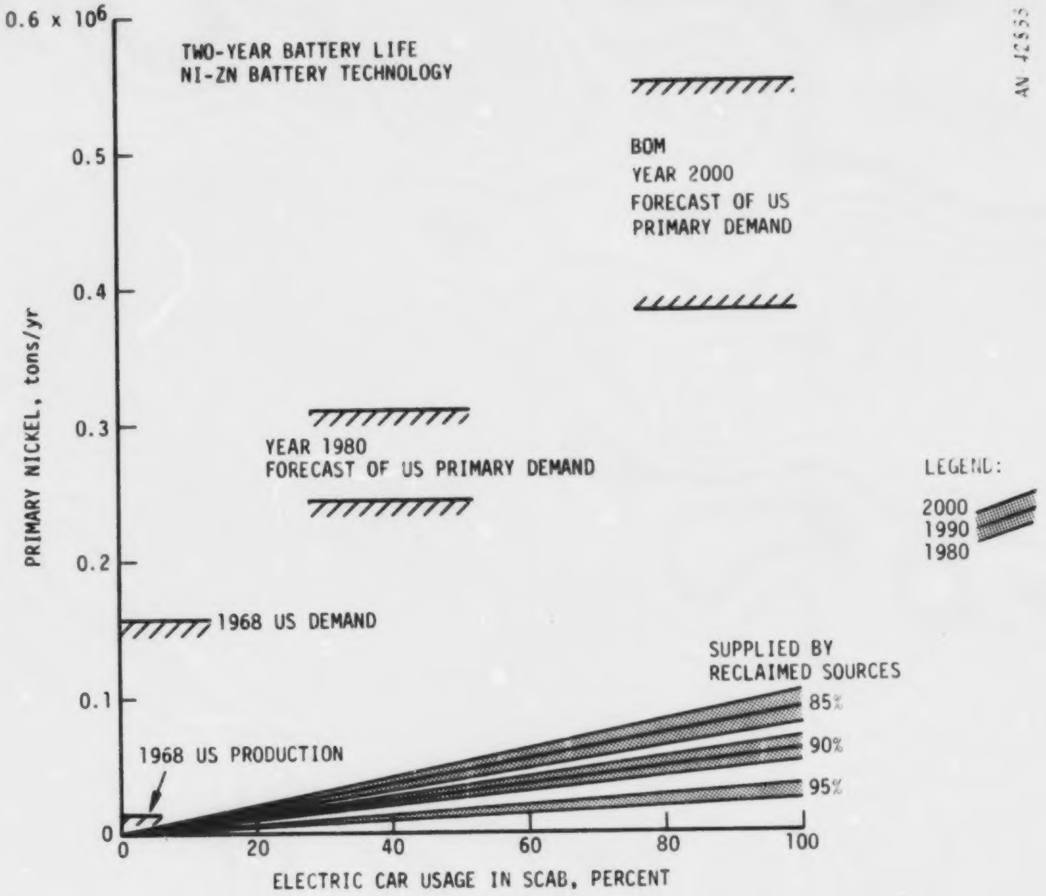


Figure 3.7. Nickel Requirement as Function of Usage In SCAB

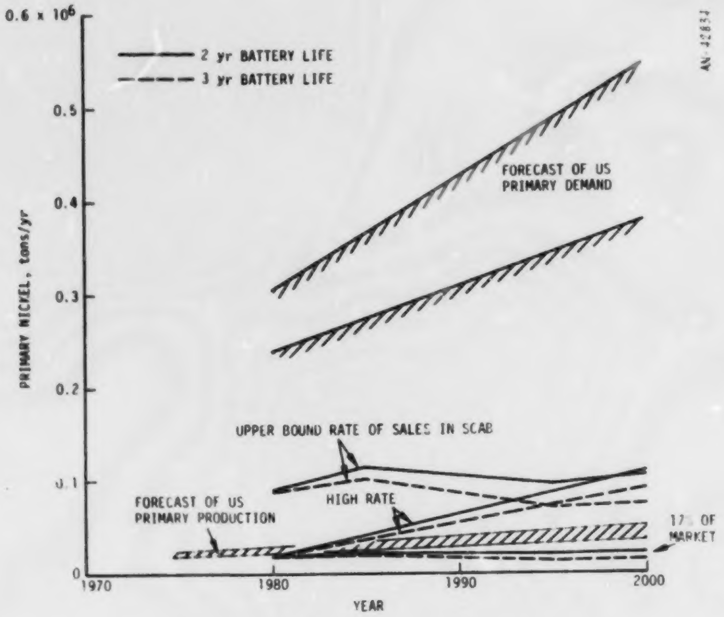


Figure 3.8. Nickel Requirement as Function of Time

high recycle efficiencies should be economically attainable.

3.1.4 Zinc

Two battery technologies requiring zinc are considered, nickel-zinc and zinc-chlorine. The former will require about four times as much zinc as the latter. Calculations of the requirement for primary zinc for 100 percent electric car usage in SCAB show that the requirement will probably cause only a very small effect on the forecast supply and demand relationship for the United States. The results of these calculations for both cell technologies are summarized in Table 3.3, along with the Bureau of Mines forecast for US domestic primary demand and production. The electric car requirements shown in the table are for 100 percent electric car usage within SCAB at two levels of supply from reclaimed sources, 85 percent and 95 percent. The SCAB estimates have also been scaled to estimates for 100 percent electric car usage within the US.

TABLE 3.3

ANNUAL REQUIREMENT FOR NEW ZINC TO SUPPORT SCAB ELECTRIC CAR USAGE

(100 percent Electric Car Usage in SCAB*)

	Zinc Demand, Thousands of Tons	
	1980	2000
Nickel-Zinc Batteries, 2 yr Life		
85% Supplied from Reclaimed Sources	58 (814)	75 (1050)
95% Supplied from Reclaimed Sources	19 (271)	25 (350)
Zinc-Chlorine Batteries, 2 yr Life		
85% Supplied from Reclaimed Sources	14 (196)	18 (255)
95% Supplied from Reclaimed Sources	4.7 (66)	6.1 (85)

US Zinc Availability	1968	1980	2000
Primary Demand	1406	1600 2300	2040 4000
Primary Production	529	600 870	786 1500

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*Total US in parentheses.

Comparison of SCAB requirements for primary zinc under any of the conditions represented in Table 3.3 with US primary demand for zinc indicates that there should be little effect on the BOM forecasts. Even zinc requirements for a 100 percent electric car usage on a national level may be accommodated, especially with the lesser demands inherent in the zinc-chlorine cell.

Under 1968 conditions, reclaimed zinc provided for only 15 percent of the total demand. This is partly due to the fact that significant portions of the zinc supply are provided for end uses in which the zinc is not easily recoverable, e.g., zinc galvanizing. Battery zinc, however, should prove to be highly recyclable, given sufficient economic incentives. Since the BOM expects zinc prices to double by the year 2000 (in 1968 dollars) in order to bring supplies into equilibrium with demands, the incentive to recycle zinc should improve.

Presently the US depends to a significant degree on foreign sources of zinc, as implied by Table 3.3, and the BOM expects this situation to continue to the same degree. Zinc and lead are generally co-products of the same extraction process. Consequently future expectations for the supplies and demands of these materials must take into account this interdependence and the possibility of large-scale use of electric cars employing first lead-acid batteries with a later shift to one of the zinc-based batteries.

3.1.5 Titanium

For the zinc-chlorine battery configuration adopted in Ref. 7, approximately 50 pounds of titanium per battery is necessary for electrode and heat exchanger construction for the four-passenger electric car configuration. Based on this requirement, the annual quantity of primary titanium metal to support various levels of electric car usage in SCAB was calculated. The results of these calculations are summarized in Table 3.4 for the conditions of 100 percent electric car usage for each

TABLE 3.4

ANNUAL REQUIREMENT FOR NEW TITANIUM TO SUPPORT ELECTRIC CAR USAGE IN SCAB

(100 percent Electric Car Usage in SCAB)

	Titanium Demand, Thousands of Tons		
	1980	1990	2000
Two-Year Battery Life			
85% Recycle	11.0	12.8	14.3
90% Recycle	7.3	8.5	9.5
95% Recycle	3.7	4.3	4.8

	US Titanium Supply and Demand, Thousands of Tons	
	1968	2000
Titanium Primary Demand as Compounds	440	960-2160
As Metal	13	62-234
Titanium Primary Production as Compounds	305	670-1610
As Metal	0	0

of the years 1980, 1990, and 2000, for three assumed levels of supply from reclaimed sources, and for a two-year battery life. Also shown are the 1968 estimates of US total and primary demands for both titanium metal and compounds, as well as the year-2000 forecast for these same demand categories.

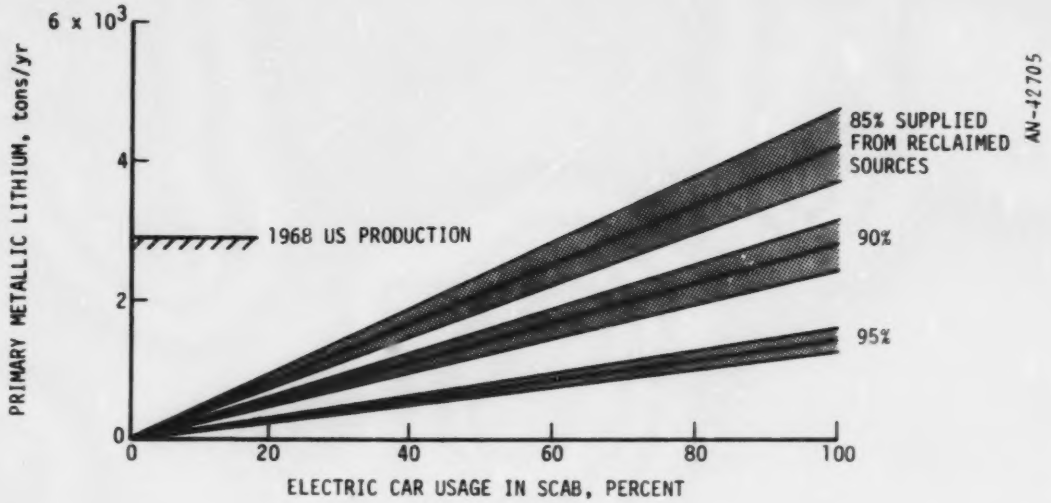
A comparison of electric car requirements with 1968 titanium demands shows that the production of metal would have to be increased significantly. However, existing demand for metal is such a small fraction of total titanium demand that overall titanium supplies should be little perturbed. The forecast shows that titanium metal demand should expand faster than total demand, owing primarily to its importance in many advanced-technology systems. Should such an expansion of titanium metal demand occur, other advanced systems employing titanium, such as the zinc-chlorine cell, should benefit from the concomitant expansion in the economic supply of the metal.

Titanium "sponge metal" was priced at $1.32 per pound in 1968, and the BOM forecast expects that this price should remain more or less constant to the year 2000. However, the electrolytic processing of titanium compounds to yield sponge metal uses from 6 to 15.5 KWH per pound, plus another 2 to 2.5 KWH per pound to produce metal ingot from the sponge. Expected higher costs for energy may cause the finished metal prices to rise womewhat above the BOM forecasts. In any case, titanium is expensive enough that there should be ample incentive for recycling.

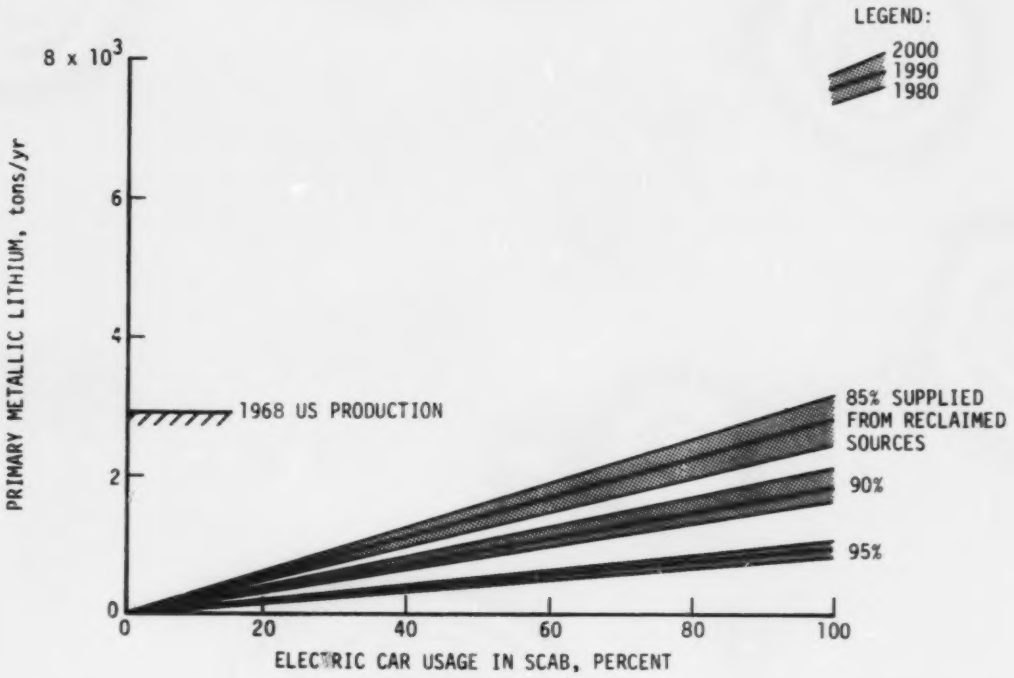
Table 3.4 also shows that the US produces virtually no titanium metal in this country, relying solely on foreign sources. This situation arises because of the suitability of different ores for processing into metal. According to the BOM, the most suitable ores are in foreign countries, although there are some deposits here in the US.

3.1.6 Lithium

Improvements in electric car performance and range depend on the development of advanced battery systems. Lithium-sulfur batteries have been proposed as a promising candidate. The four-passenger electric car configuration described in Ref. 7 utilizes a battery system containing 16.7 pounds of lithium, 68.1 pounds of sulfur, and 22.8 pounds of porous graphite along with small amounts of other commonly available materials (steel, aluminum, etc.). SCAB electric car requirements for lithium as a function of electric car usage are presented in Fig. 3.9, under the assumption that lithium in batteries will be recycled.



(a) Two-Year Battery Life



(b) Three-Year Battery Life

Figure 3.9. Lithium Requirement as Function of Usage in SCAB

The bulk of lithium used today is consumed in lithium compounds. As a result lithium (as well as graphite) is virtually unrecycled under present conditions. Consequently, we show for lithium in Fig. 3.10 the annual amounts required as a function of electric car usage under the assumption that no material is supplied from reclaimed sources. However, since the lithium used in electric cars is metallic lithium, which is very expensive, we would expect its use to initiate a vigorous recycle effort in metallic lithium, in which case Fig. 3.9 is more appropriate.

Lithium may become an even more important material beyond 2000 if the development of fusion power is successful. The less abundant lithium-6 (Li^6) isotope will probably be a central material for a fusion process. In that case, the mineral production and processing to retrieve the Li^6 isotope would have the very abundant Li^7 isotope as a byproduct, which would undoubtedly enhance the economic supply of lithium for other uses.

Figure 3.11 presents the growth of SCAB electric car requirements for lithium over the time period 1980 to 2000 for several selected scenarios. Two cases in which no recycle is assumed, and one case with recycle, are shown and compared with forecast US lithium production. It is noteworthy that, even with recycle, Fig. 3.11 shows that either an "upper bound" or "high" introductory rate of electric car sales in SCAB will have a significant impact on the forecast of lithium production.

2.1.7 Graphite

SCAB electric car requirements for graphite (used as electrode material) have been calculated as a function of electric car usage and are presented in Fig. 3.12. Recycling is not considered, since graphite is presently not recycled and its cost is not high. However, SCAB requirements are significant when compared to the forecast of total US demand. Furthermore, the US produced only about 5 percent of its 1968 demand, relying on foreign sources for the remainder. There are significant

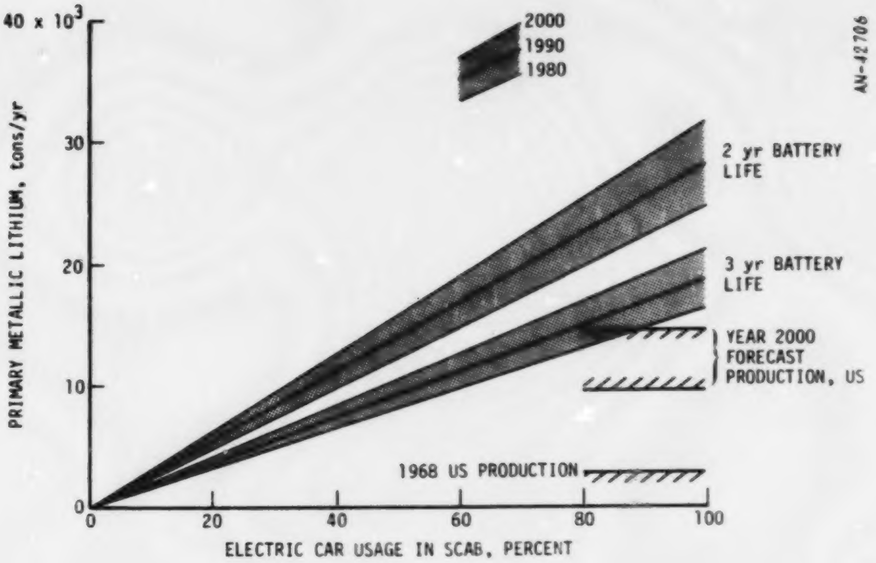


Figure 3.10. Lithium Requirement as Function of Usage (No Recycle)

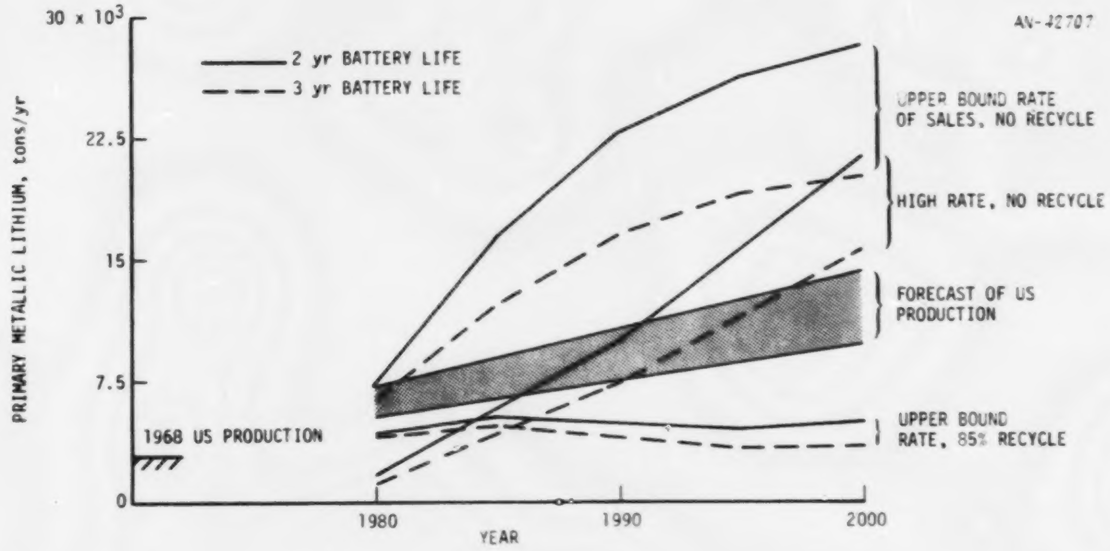


Figure 3.11. Lithium Requirement as Function of Time

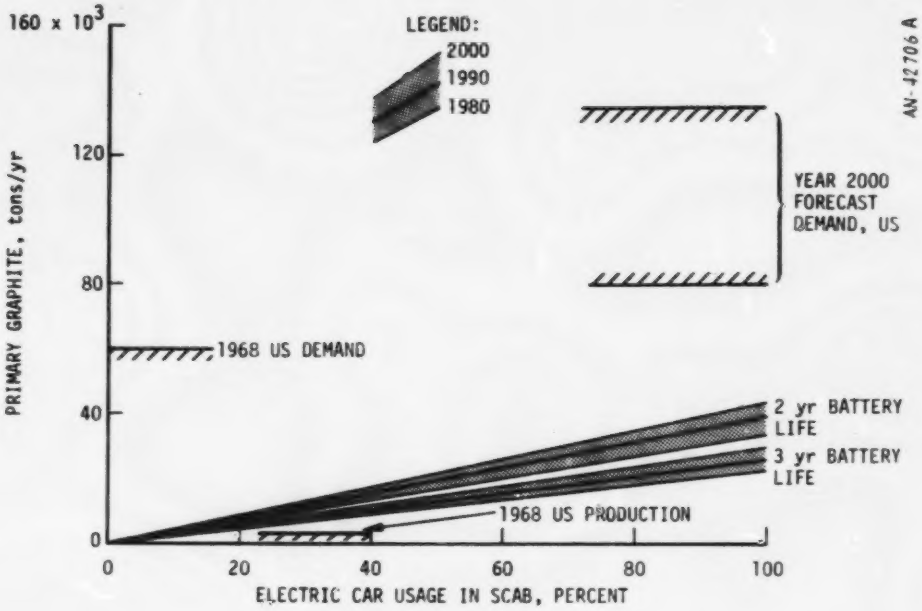


Figure 3.12. Graphite Requirement as Function of Usage in SCAB (No Recycle)

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graphite reserves in the US, but the particular end uses of graphite require physical characteristics more readily attainable from foreign sources, a situation which is likely to persist.

Figure 3.13 presents the graphite requirements as a function of time over the period 1980 to 2000 for two electric car sales scenarios, and also relates these requirements to forecast US demands.

3.1.8 Other Materials

SCAB electric car requirements for sulfur (in the lithium-sulfur cell) and copper (in motors) have been calculated. Based on high utilization rates of electric cars in SCAB, and no recycling of the material, the requirements for each of these materials represent small fractions of the existing and forecast demands. SCAB requirements at 80 percent electric car population are 1.1 percent and 0.46 percent of 1968 demands for sulfur and copper respectively. We assume that battery sulfur is

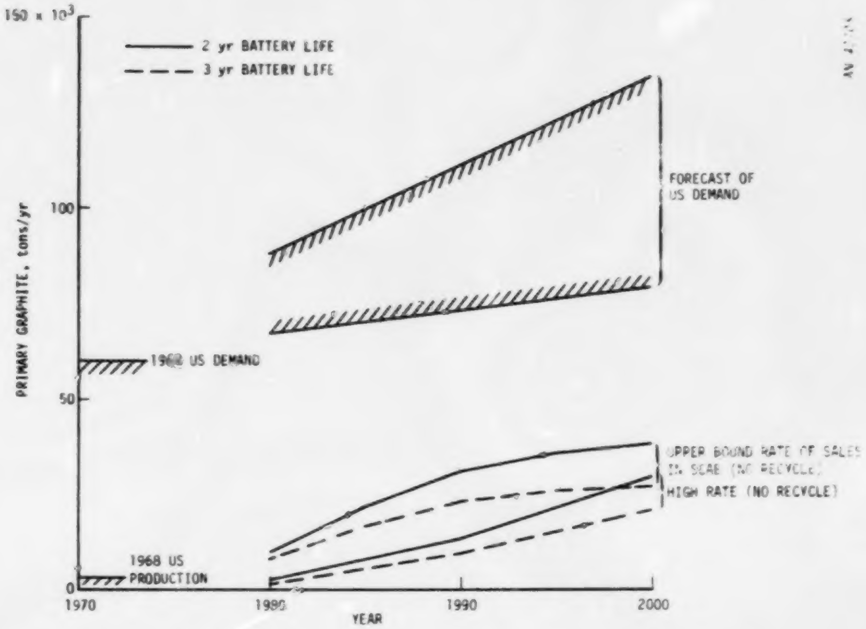

Figure 3.13. Graphite Requirement as Function of Time

not recycled, and that copper in the motor and car is only recycled when the car's life expires (approximately 17 years life span, 50 percent surviving at 11.5 years), which leads to inconsequential levels of recycled material until after one life span period has passed in the buildup of the electric car population.

Sulfur supplies are plentiful, and present environmental concerns to remove sulfur from fossil fuels, and consequently make sulfur available as a byproduct, promise to add further to supplies.

Although SCAB requirements are an insignificant factor in US copper supply and demand, we should note that the US depends on the rest of the world for approximately 25 percent of its total demand for copper. The US has significant copper reserves of 85.5 million tons, to which must be added the approximately 40 million tons of copper in use. Copper is reclaimed to a significant degree, which lends importance to the in-use reserve. World reserves were estimated in 1968 to be slightly more than three times US reserves. Demand growth in other developed countries has been substantial and is expected to continue. Consequently, world supplies cannot be considered plentiful.

Chlorine gas to supply zinc-chlorine batteries should be in plentiful supply. A 100 percent electric car inventory in SCAB in the year 2000 represents about 270,000 tons of chlorine in use; this amount is only 3 percent of the 1968 US production. Thus even high rates of buildup in the electric car population using zinc-chlorine batteries would be an insignificant contributor to total US demands for chlorine.

3.1.9 Summary of Impacts on Mineral Supplies and Demand

In the previous paragraphs the materials requirements for various levels of SCAB electric car populations and usage have been quantified. These requirements then are compared to historical and forecast supply and demand relationships developed by the BOM.[18] In general, the forecast relationships do not explicitly account for the advent of electric cars on any significant scale, although the importance of particular minerals to such a development is noted. Instead the forecasts by the BOM reflect considered, expert judgments of the effects of known technologies on future growth trends. Consequently, electric car requirements represent variations from the underlying considerations in the forecasts and should be judged as additions to the forecast levels.

In Table 3.5 we summarize the electric car impacts on mineral resources for the most important materials for each battery technology. The table presents the present and year-2000 forecast production and demands, and compares them to the estimated requirements for particular levels of electric car usage within SCAB, selected to reflect the appropriate time period for each battery technology and corresponding sales expectations. The annual material requirement to support electric car usage in SCAB is based on a two-year average battery life and a 90

TABLE 3.5

SUMMARY OF RESOURCE IMPACTS

		Quantities, Thousands of Tons per Year							
		US Primary Production		US Primary Demand		Equilibrium[*] Annual Electric Car Requirement for New Material with 2-Year Battery Life and 90% Recycle (SCAB)	Usage Conditions (SCAB Level and Year)	Potential Problem ((Electric Car Requirement as Percent of National Primary Demand for Given Usage Year)	
Battery Type	Material	1968	2000 (Range)	1968	2000 (Range)			SCAB Implementation	Nationwide[**] Implementation
Lead-Acid	Lead	354	520-1,120	880	1,300-2,800	22	17%, 1980	1.7%	33%
	Antimony	1.9	2.5-4.8	21.1	28-52	0.6	17%, 1980	2.1	43
Nickel-Zinc	Nickel	15	36-52	160	382-550	29	46%, 1990	7.8	157
	Zinc	529	786-1,500	1,406	2,040-4,000	20	46%, 1990	0.8	16
Zinc-Chlorine	Zinc					12	100%, 2000	0.4	8
	Titanium (metal)	305 (0)	670-1,610 (0)	440 (13)	960-2,160 (62-234)	9.5	100%, 2000	0.6	12[++]
	Chlorine	8,400	26,400-43,900	8,400	26,400-43,900	130[+]	100%, 2000	0.4	8
Lithium-Sulfur	Lithium	2.9	9.4-14.4	2.6	8.7-13.1	3.2	100%, 2000	29[++]	587[++]
	Graphite[+]	3.0	4.0-4.7	60	80-135	43[+]	100%, 2000	40	800
	Sulfur[+]	11,000	28,000-45,000	10,000	26,000-41,500	130[+]	100%, 2000	0.4	8

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[*] Equilibrium conditions for the fraction of electric cars in the total population are assumed; that is, the electric car population fraction is relatively constant and not undergoing any long-term buildup.

[**] The scaling factor to be applied to the "Annual Requirements" column for nationwide electric-car use is approximately 20.

[+] No recycle assumed.

[++] Electric car requirements for these materials would impact on production capacity for metallic forms.

percent recycle rate.

In summarizing the impacts, the most significant comparisons to be made are between the estimated primary demand and the electric car annual requirement. The column headed "US Primary Production" is presented for comparison with primary demand, to demonstrate sensitivities to foreign sources. The impacts are qualitatively assessed in the last columns, which show an "X" where a SCAB (or nationwide) implementation at the assumed usage level would pose a significant problem for that material's supply and demand situation. It must be remembered that in general a rapid buildup in electric car population, say 10 years to achieve the assumed usage level, can increase the annual requirement for a given material by a factor of two over those shown in Table 3.5. In those cases, where assumption of a two-year battery life and a 90 percent recycle rate may be overly conservative (e.g., nickel-zinc batteries), the requirement would undoubtedly be constrained by the rate of buildup in the electric car population.

Assuming that a material requirement which exceeds 20 percent of that material's projected national primary demand in the year identified for usage conditions represents a significant impact, potential problems are identified for SCAB implementations involving only lithium-sulfur. On this same basis, potential problems for a national implementation are identified with at least one material for each of the four battery technologies. However, as noted in the table, the impacts on titanium and lithium supply and demand are associated with production capacities of the metallic forms rather than resource availability. For lithium metal, electric car requirements exceed the total of all other demands, but lithium reserves are more than adequate. There are large worldwide reserves of both nickel and graphite, so that it is feasible to consider even greater expansions in demand than the forecasts shown in the table.

3.2 US AND WORLD RESERVES OF ELECTRIC CAR MATERIALS

The forecasts of future supply and demand relationships have taken into account the estimated levels of both US and world reserves. In this section we briefly review the estimates of these reserves of electric car materials.

Estimates of US and world reserves of minerals must be viewed with some caution. By definition, "reserves" refers to the known availability of resources that can be economically recovered at prevailing or reasonable future prices. Hence, estimates are quite often conservative in that they do not adequately allow for new technologies which can make profitable heretofore uneconomical sources. In this sense, technology is very likely to be as important as new geological discoveries in enhancing the economic supplies (reserves) of minerals. Quite often it is the coincident effects of price increases and new technology that bring about significant expansions in supply. The supply of nickel is a good case in point: present prices have provided sufficient incentive to process the lateritic nickel deposits (a low-grade ore), which are much more widespread than the sulfide deposits previously relied on. As a result, world nickel reserves have been augmented manyfold.[21] Only a small amount of the lateritic ores of known quality and profitability are included in the Bureau of Mines (BOM) estimates of world reserves. None-the less, recognizing that in most cases the BOM estimates of reserves are probably conservative for the reasons stated above, we present in Table 3.6 the BOM estimates of US and world reserves for those materials deemed most important to electric car production and use. Also shown in Table 3.6 is the estimated total amount in use for a 100 percent SCAB electric car inventory in the year 2000. As indicated in the table, US reserves of lead, lithium, zinc, and titanium appear adequate; graphite reserves are marginal; and antimony reserves would leave little for other uses. US nickel reserves under BOM estimates appear inadequate. However, world reserves of antimony, graphite, and nickel appear to be adequate, although their availability may be subject to more uncertainty than domestic sources.

TABLE 3.6

ESTIMATED US AND WORLD RESERVES

Quantities, Thousands of Tons

	US Reserves	World Reserves	Amounts in Use, 100% SCAB Electric Car Inventory, Year 2000	100% National Electric Car Inventory, Year 2000*
Lead	39,000	99,000	3,550	71,000
Antimony	110	4,000	91	1,820
Lithium	5,254	6,036	64	1,280
Graphite	600	$\sim 10^5$	106	2,120
Nickel	900	>75,000	1,360	27,200
Zinc	78,000	90,000	Ni-Zn 1,000	20,000
			$Zn-Cl_2$ 240	4,800
Titanium	25,250	160,000	188	3,760

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*SCAB levels scaled by factor of 20.

Figures 3.14 to 3.20 show in more detail the total amounts of critical materials in use in electric cars in SCAB as a function of the electric car population for the years 1980, 1990, and 2000. Existing and forecast primary production rates are shown for reference, and also as an indication of the limitation that material production might enforce on the rate of buildup of the electric car population in SCAB. These curves should be scaled by a factor of 20 to provide estimates of amounts of material in use for a nationwide implementation of electric cars.

3.3 RESOURCE IMPLICATIONS OF A NATIONAL IMPLEMENTATION

The previous discussion has dealt primarily with the impact of electric car use within the Los Angeles region on the US supply and demand balances. SCAB population is about 5 percent of the total US; thus, we can obtain a rough estimate of the resource implications of a national implementation of electric cars by scaling the previous curves by a factor of 20. Clearly lead and antimony supplies could support only a small percentage of electric car use on a national scale, but this is consistent with the low expectation of an electric car future based only on lead-acid battery technology. Electric cars using lithium-sulfur cells will place significant demands on lithium supplies. However, the availability of large US reserves plus the anticipated development of a recycle market in metallic lithium should prove sufficient. Only the rate of buildup of electric car population based on future technology may be limited by the rate at which lithium refining and processing capacity may be expanded. Graphite requirements on a national scale will further exacerbate our dependence on foreign sources, which on a physical bases seem sufficient. If worldwide availability of resources were the constraining factor, it would be feasible, based on estimated world reserves, to consider national implementations of electric cars employing either nickel-zinc or zinc-chlorine battery technology.

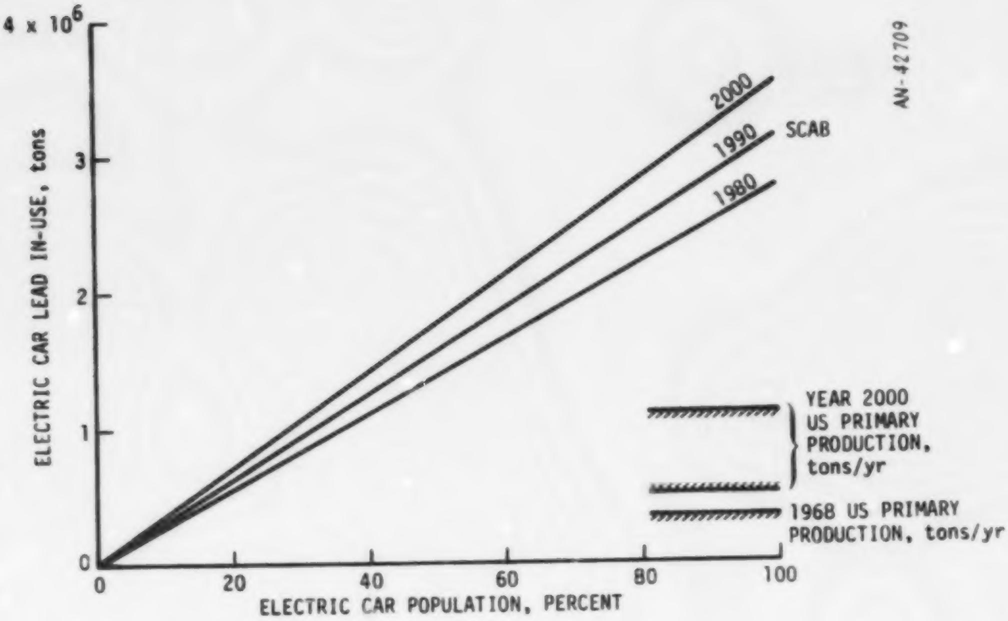

Figure 3.14. Electric Car Lead Inventories (Lead-Acid Batteries)

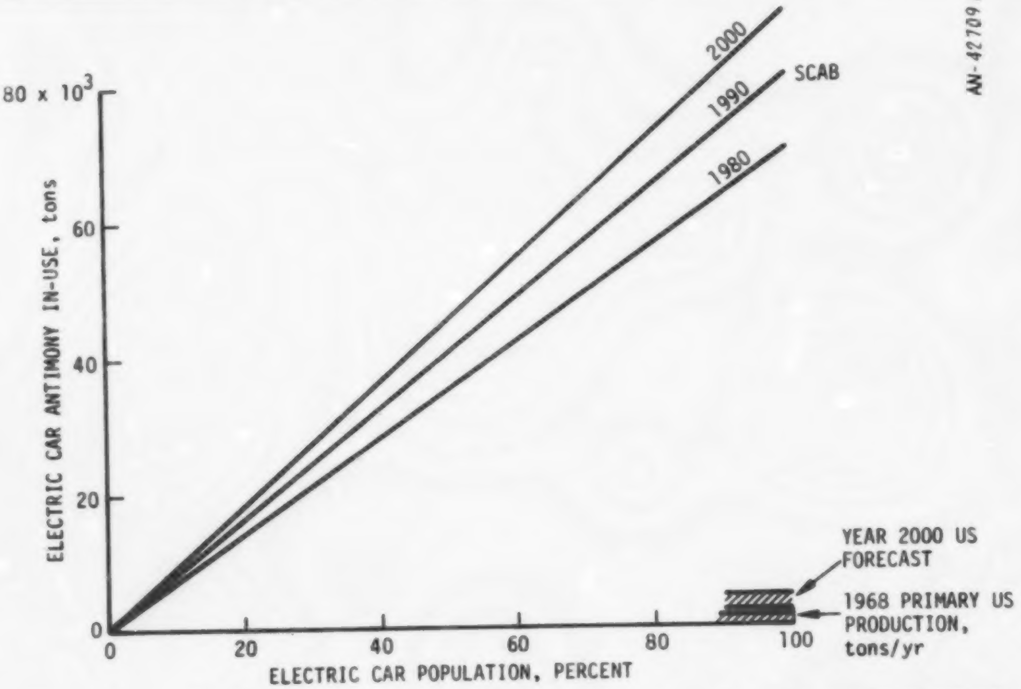

Figure 3.15. Electric Car Antimony Inventories (Lead-Acid Batteries)

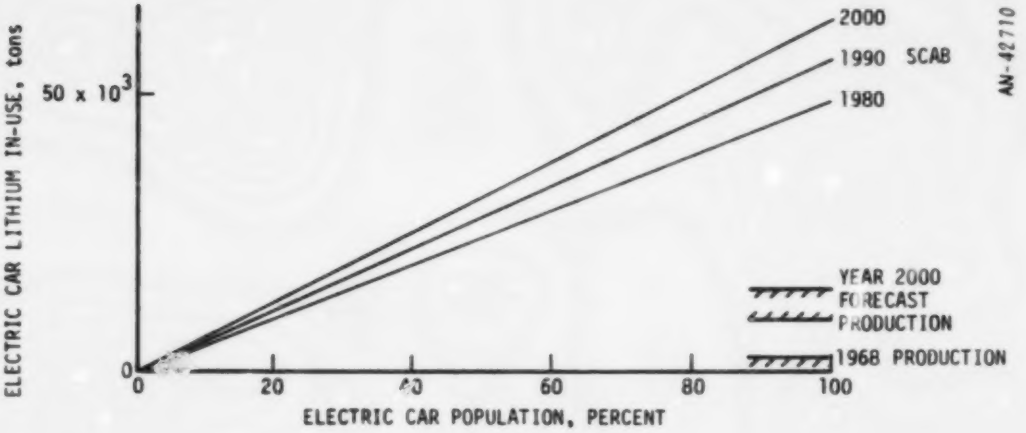

Figure 3.16. Electric Car Lithium Inventories (Li-S Batteries)

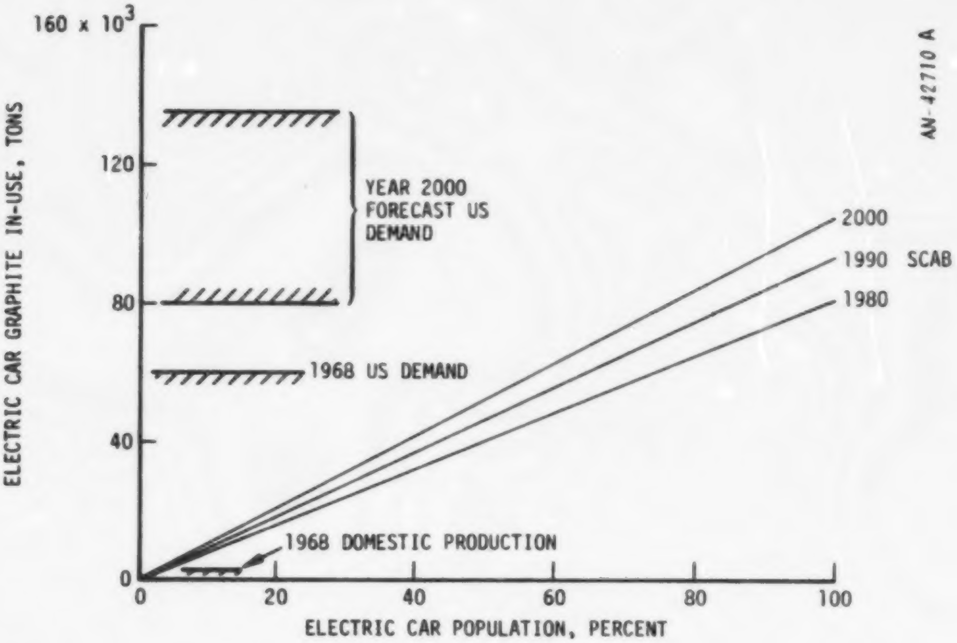

Figure 3.17. Electric Car Graphite Inventories (Li-S Batteries)

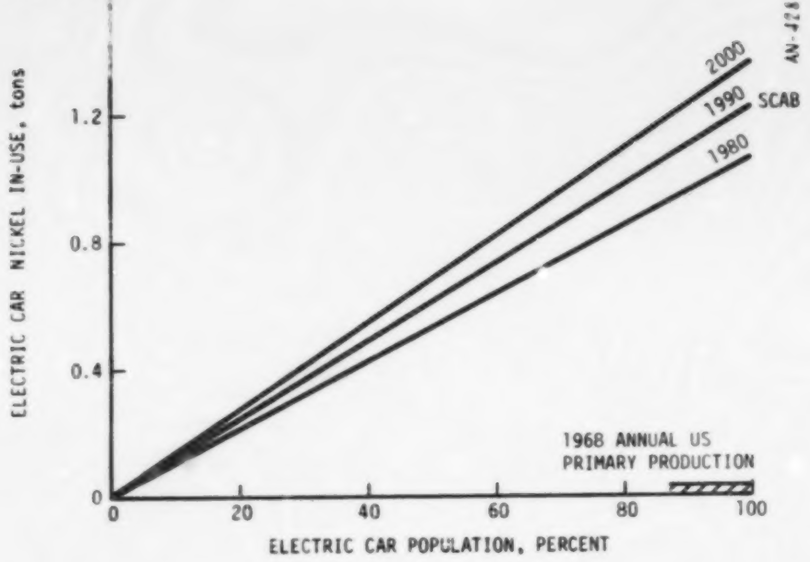

Figure 3.18. Electric Car Nickel Inventories (Ni-Zn Batteries)

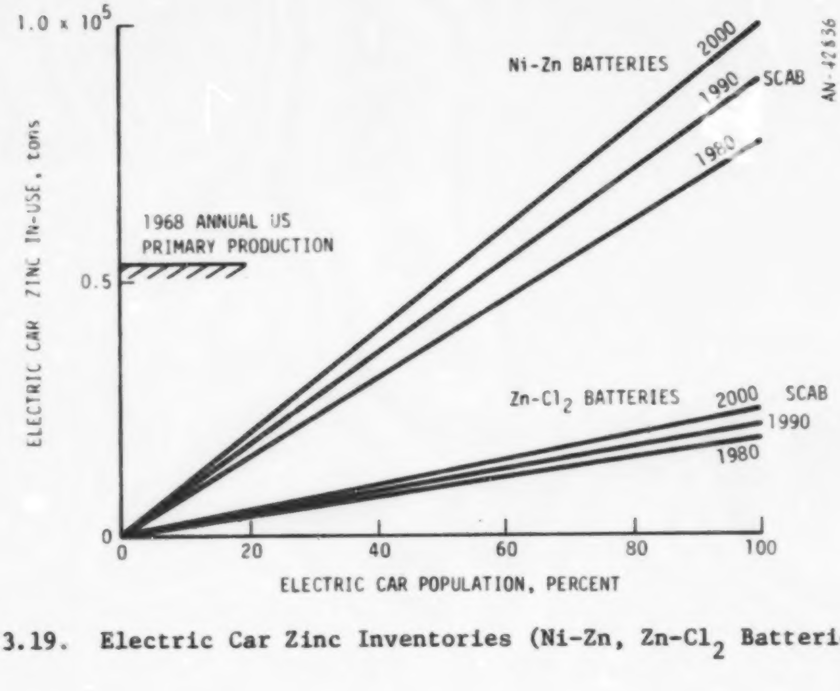

Figure 3.19. Electric Car Zinc Inventories (Ni-Zn, Zn-Cl_2 Batteries)

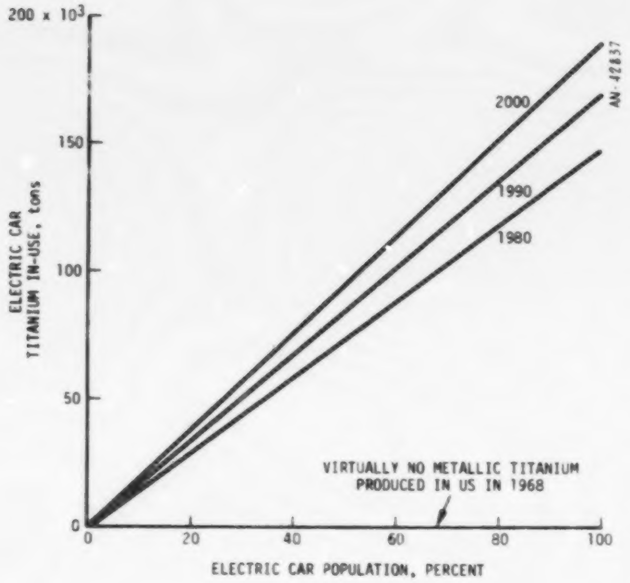

Figure 3.20. Electric Car Titanium Inventories (Zn-Cl_2 Batteries)

3.4 PRICE TRENDS OF MINERAL RESOURCES

The Bureau of Mines has also made forecasts of prices out to the year 2000 for most of the mineral resources. Price forecasts take into account expected future demands, both US and worldwide, and the corresponding availability of reserves. The BOM estimates, which are in constant 1968 dollars, are presented in Table 3.7 for each of the materials discussed in Sec. 3.1. Also shown for reference are some recent commodity market quotations, where available, for these materials.

In general a significant increase in the forecast for a commodity's price indicates the relative scarcity of that commodity. Thus, according to the BOM forecasts, antimony, copper, nickel, and zinc are likely to be relatively scarce well into the future. All the current prices are well above the levels forecast by the BOM. One reason, of course, is the substantial inflation that has occurred since 1968. Another is the unforeseen energy crisis, which has resulted in increasing the costs

TABLE 3.7

PRICE TRENDS OF MATERIALS IMPORTANT TO ELECTRIC CARS

	BOM Estimates, 1968 Cents per Pound		Current Spot Prices (May-June 1974), 1974 Cents per Pound
	1968	2000	
Lead	13.5	11.5	21.5-24.5
Antimony	45.75	60	223
Lithium (Metallic)	750 to 1100	750 to 1100	
Graphite (Crystalline)	7.2	7.2 9.5	
Sulfur	2.1	1.9 2.0	
Copper	42.2	75	82-87
Nickel	94	200	185
Titanium (Metal)	132	132	
Zinc	13.5	27	36-40

of the energy associated with the production of any material. Furthermore, because of existing inflation, these prices cannot be taken to reflect steady equilibrium prices for supply and demand relationships. For example, the prices of copper "futures" are running well above 50 percent higher than the present spot prices. Also some of these materials have had significant momentary price rises in their history. In 1970 antimony reached a level of 178 cents per pound for four months; yet in the following year (1971) the price averaged out at 71.3 cents per pound.[19]

Price rises in these materials that persist for any length of time may provide the incentive for establishing secondary supply sources.

Lead and antimony are already highly recycled and copper moderately so. Consequently, further price increases in lead and antimony can do little to improve recycle rates and may instead initiate the utilization of cheaper, alternative materials where possible. Copper recycling will undoubtedly benefit from the high prices.

Because of the highly volatile price behavior of many commodities, it is difficult to estimate what changes might be occurring to affect the long-term prices. Of those materials that may be significantly affected by electric car demands, primarily lithium, there is no firm basis upon which to estimate future prices. For lithium, with its apparent large reserves in this country, we would expect prices to vary little from the BOM forecasts in terms of 1968 dollars. However, some correction may be required for the costs of energy used in the electrolytic production of metallic lithium.

3.5 OTHER RESOURCE CONSIDERATIONS

Throughout the discussion of each material's supply and demand relationship, the critical importance of secondary supplies (recycling) was stressed, especially for those materials of greatest scarcity. Based on past trends, the development of significant recycle efforts has depended most strongly on direct economic incentives, primarily high costs for processing primary sources. However, it is reasonable to expect other incentives to reinforce trends to greater recycling, such as greater difficulties posed in the elimination of scrap as solid waste. It has previously been mentioned that spent battery cases and used electrolyte pose just such a situation.

Presently batteries are recycled to a significant degree because of the scrap value of lead. However, increasing environmental sanctions are inhibiting the easy disposal of scrap cases by burning, or of used electrolyte by flushing down the sewer. Thus, these waste products are beginning to take on nuisance values which conceivably may make it more profitable, for example, to recycle battery cases than pay the extra costs to dispose of them cleanly.

In the case of electric car batteries, which will have significantly greater costs, the inherent value of the battery case may be appreciable and so designed to be readily re-used. Battery depreciation may be the most significant operating cost of an electric car; recycling of the case as well as the valuable metal may significantly decrease these depreciation costs. Thus nuisance value as a solid waste problem, combined with likely high battery depreciation costs, can act in concert to enhance recycling of materials.

Electrolyte for lead-acid batteries will not be costly and so will little affect battery depreciation costs. Only its nuisance value and the ease with which it can be restored to its useful state will dictate whether battery acid will be recycled.

With regard to the advanced-technology batteries employing unique features such as refrigeration systems or heating systems, there will doubtless be some high-value components for which sufficient incentive to recycle them should develop. In general where estimates of battery depreciation costs would otherwise be high, there will be a strong tendency to recycle materials and components. As a consequence, electric cars will probably pose less of a solid waste problem than conventional autos (e.g., as pointed out in Ref. 10, there are apparent existing problems in the disposal of waste lubricating oils from conventional cars that will not be characteristic of electric cars).

4 POTENTIAL IMPACT OF SCAB ELECTRIC CARS ON URBAN NOISE

It has already been suggested[10] that electric cars, by virtue of having no internal combustion engine, may be quieter vehicles to operate. The widespread use of a large number of quieter vehicles may have an effect in reducing urban noise levels. Concern over rising noise levels in communities is increasing and legislative actions are becoming more prevalent. Accordingly, we examine in this section the impacts of electric cars on urban noise levels.

4.1 URBAN NOISE ENVIRONMENTS

The level of urban noise has been found to vary greatly in magnitude and character among various locations throughout a community. Evaluations of typical urban noise environments show a residual or background noise level that is low at night and increases in the morning to a level that holds throughout the day and early evening.[22] Superimposed upon the residual level are many random instances of significant noise intrusions, the character of which depends on activities peculiar to each neighborhood or area of the community. In general, aircraft and nearby automobile operations constitute the most prevalent and significant forms of intrusive noise. Noise intrusions are instances that are usually quite easily characterized as to the source (e.g., sports car accelerating, dog barking, aircraft taking off, etc.), and are distinct from the general din generated by continuous traffic and other general human activity.

The effects of noise pollution on human activities depend on the kind of activity and whether it is being conducted indoors or outdoors. The effect of the noise may be merely annoying or may greatly interfere with the activity. A great deal of research has been conducted in the development of noise scales that attempt to quantify the intrusive, annoying, or interfering qualities, among others, of noise. No single scale has been found entirely satisfactory for all aspects. One convenient scale that has been found generally appropriate for overall noise surveys is the "A-weighted noise scale," which weights the spectral content of a sound in accord with the average spectral sensitivity of the human ear.

The Environmental Protection Agency has conducted and reported[22] on surveys of outdoor community noise, utilizing primarily A-weighted sound measurements. Eighteen outdoor environments were surveyed, ranging from the Grand Canyon to a third-floor apartment next to a freeway. We have selected the survey results for five of those locations as representative environments for electric car studies. Table 4.1 presents a summary of the results for the five selected locations in terms of the noise levels that were exceeded 99, 90, 50, 10, and 1 percent of the time during the daytime hours. The 90 percent level closely represents what may be interpreted as the residual or background noise level.

The table is arranged in descending order based on background or residual noise level. For the other levels, the locations follow the same order, with the exception of the location near a major airport. The effect of airport operations is manifest in the less frequent intrusions of aircraft noise at significantly higher levels relative to the

TABLE 4.1

A-WEIGHTED OUTDOOR NOISE LEVELS

Decibels Above 20 $\mu N/m^2$ (dBA)

	Level Exceeded x% of Time				
	x = 99%	90%*	50%	10%	1%
Third Floor Apartment, Next to Freeway	76	77	80	85	89
Third Floor High-Rise, Downtown Los Angeles	69	72	77	82	86
Urban Shopping Center	59	62	64	69	72
Urban Residential Area Near Major Airport	49	53	59	76	93
Urban Residential Area	46	47	52	58	66

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*Effective residual or background level.

background. The ordering of the table also correlates well with descending auto traffic environments, which may be important sources of background noise levels.

Widescale utilization of electric cars will undoubtedly affect traffic noise in any of the environments typified in Table 4.1. The significance of that effect will depend on the electric car's inherent noise generation relative to the conventional auto it displaces, and the relative usage it obtains. One effect of electric cars thus may be to alter the background levels slightly.

Even if it were to be shown that electric cars might reduce background noise levels, it is not certain that the reduced background would be an improvement; in many instances there is adaptation to background noise, and it is the momentary intrusions which are annoying. However, in situations of high background levels, such as exemplified in the first location of Table 4.1, reductions in that level will very likely represent an improvement.

On the other hand, noise intrusions most often cited as interfering usually entail one single recognizable noise source such as a poorly muffled auto or motorcycle undergoing acceleration on a street very near to the recipient of the noise. The background may be anywhere from 10 to 40 dB lower in noise level than the intrusive source, as seen by comparing the 90 percent and 1 percent levels in Table 4.1. Electric cars may have an even greater effect on reducing occurrences of such intrusions.

4.2 COMPARISON OF ELECTRIC AND CONVENTIONAL AUTO NOISE GENERATION

R.J. Vargovick of the Ford Motor Company reported[23] on noise measurements for several types of autos under various operational modes. Tests were conducted to study the relative significance of exhaust, tire-road interaction, and fan noises in total auto noise. Table 4.2 summarizes the results of those studies, showing the A-weighted sound levels

TABLE 4.2

EXTERIOR NOISE LEVELS FOR VARIOUS CONDITIONS AND 1970 VEHICLE TYPES

	dBA at 25 ft Distance							
	35 mph				65 mph			
Mode of Operation	High-Power Sedan	Low-Power Sedan	High-Power Sporty Compact	Low-Power Sporty Compact	High-Power Sedan	Low-Power Sedan	High-Power Sporty Compact	Low-Power Sporty Compact
Cruise	66.5	67.5	70.0	68.2	74.5	77.7	78.7	79.2
Cruise (no fan)	65.5	66.0	71.0	68.7	74.5	75.5	78.5	78.7
Coast (engine off)	65.5	64.8	66.0	68.2	74.0	75.7	76.0	78.0
WOT*	88.3	80.8	87.2	87.2	89.5	82.5	88.7	87.7
WOT (two mufflers)	82.5	--	--	--	--	--	--	--
WOT corrected to 50 ft	82.3	74.8	81.2	81.2	--	--	--	--

NOTE: Production tires for sedan--H78-15 bias belted; production tires for sporty compact--F70-14 bias belted.

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*WOT--Wide open throttle.

for several modes of operation. The individual contributions of exhaust, tire-road, and fan noise can be inferred from these data.

Of the four types of autos studied, the low-powered sedan (which we assume is an adequate representation for a compact sedan) is the most likely candidate to be displaced by electric cars. The results for this auto indicate that at 35-mph cruise conditions on a smooth concrete surface roughly half the noise occurs from tire-road contact (64.8 dBA coasting). Exhaust plus fan noise contributes the remainder. At 65-mph cruise conditions, the picture is similar except that the fan appears to be a greater contributor. However, in instances of "wide open throttle" operation, exhaust noise easily dominates over tire-road and fan noises at either speed.

It is difficult, of course, to deduce the relative contributions of each of these sources to general traffic noise, where at any given instant there is a mixture of cruising operation and various levels of acceleration (i.e., more open throttle settings). Also, tire-road noise depends strongly on the road surface as well as several other variables. Typical ranges in road surface roughness can introduce up to 7 or 8 dB variation in tire-road noise generation[23] (smooth concrete is at the low end of the range).

Under traffic conditions where speeds are likely to be nearer 35 mph, we would expect the general level of traffic noise to be the result of a large percentage of stop-and-go driving, implying frequent periods of acceleration. Under these circumstances auto exhaust noise is likely to dominate over other sources. For example, an average of 10 percent of the time spent in acceleration at a level halfway between cruise and wide open throttle would produce an integrated effective noise level 4 dB above the tire-road level (for smooth concrete). On very rough roads, tire-road noise may dominate over modest acceleration noise contributions. However, wide open throttle operations when they occur will probably dominate over all other auto noise sources.

At 65 mph, which imples cruise conditions with little opportunity for acceleration, we would expect little contribution to aggregate noise levels from instances of wide-open throttle operation. Thus the noise levels shown for 65-mph cruise conditions, for a representative mix of the autos in Table 4.2, may fairly characterize traffic noise for uncongested freeway travel.

As previously stated, electric cars will have no exhaust noise contributions; however, apart from normal tire-road and drive-train noise sources which will remain, their electric motors may also be a significant noise source. In general, an electric motor can be a source of a variety of noises ranging from purely mechanical sources such as bearing noise, unbalances, and friction, to airflow sources associated with the moving parts (which may include small cooling fans), to magnetic sources arising from magnetostrictive effects.[25] Each of these noise sources is susceptible in various degrees to mitigation through careful design and manufacture. The relative contributions of each source to total noise generation are not easily established and depend strongly on the type of motor and its application.

The requirements for a relatively light and efficient motor with the right torque-speed characteristics for electric car propulsion are sufficiently unique that it is difficult to speculate on what may be its significant noise sources. The equipment noise specifications that were met in developing the Bay Area Rapid Transit (BART) system indicate that the cooling system of the electric traction motors was the most significant noise source.[26] In particular, the cooling fan and its associated air flow paths required the greatest effort in designing for quiet operation. No mention was made in Ref. 26 of any particular difficulty with noise due to magnetic sources in the motors, and it was concluded that BART-car wayside noise levels are lower than those of current trucks and busses.

In another study[27] of train system noises, an estimating relationship was developed to predict the noise generation from electric traction motors. The relationship is given by the following expression by which sound power levels (PWL) in octave bands can be estimated as a function of motor horsepower (P) and speed (V):

$$PWL = B_r + 10 \log_{10} P/P_r + 15 \log_{10} V/V_r$$

where the B_r are the reference power levels in each octave band for the reference conditions (P_r, V_r) of motor horsepower and speed. For $P_r = 150$ hp and $V_r = 1400$ rpm , the B_r for each octave band are given as follows:

	Octave Band Center Frequency, Hz								
	31	63	125	250	500	1000	2000	4000	8000
Sound Power Level (B_r), dB above 10^{-12} watts	93	94	98	102	103	103	102	96	89

The estimating equation is based on noise measurements of more than ninety bare motors (i.e., without noise quieting enclosures) ranging in power between 1 and 4,000 hp and in speed between 450 and 3,600 rpm. The measurements included all component sources of traction motor noise: magnetic, mechanical, and aerodynamic. The reference condition produces an A-weighted sound pressure level at 25 feet of 81.6 dBA. These levels may be significantly reduced when the motor is installed as part of a vehicle with attention paid to noise quieting.

Traction motors used in electric cars will not be operated at as high a power level as the reference motor characterized above. The four-passenger electric car configuration selected for study has a peak power capability of 85 hp[7]; however, for typical driving conditions it will draw only a fraction of this power. For example, at a steady cruising speed of 35 mph, it is estimated that only 8 hp are required on a level road. On the other hand, during periods of acceleration considerably more power will be required.

Operating motor speeds for different electric car configurations may vary widely, since motor designers are relatively free to juggle this parameter in optimizing motor design. In one study of electric vehicle systems,[28] characteristic rated speed was allowed to vary between 6000 and 12,000 rpm. Other electric-car designs[29-31] have considered motors with rated speeds in the 3,000-to-4,000-rpm range. Rated motor speeds will be achieved only at top speed or when changing gears while accelerating; otherwise motor speeds will generally be much lower.

Traction motor noise for electric cars undergoing acceleration was calculated using the above described estimating relationship with design motor speed as a parameter. Figure 4.1 presents the results of those calculations and compares the electric motor noise levels with the values reported for conventional autos at wide open throttle presented in Table 4.2. It is assumed that maximum acceleration levels will most frequently

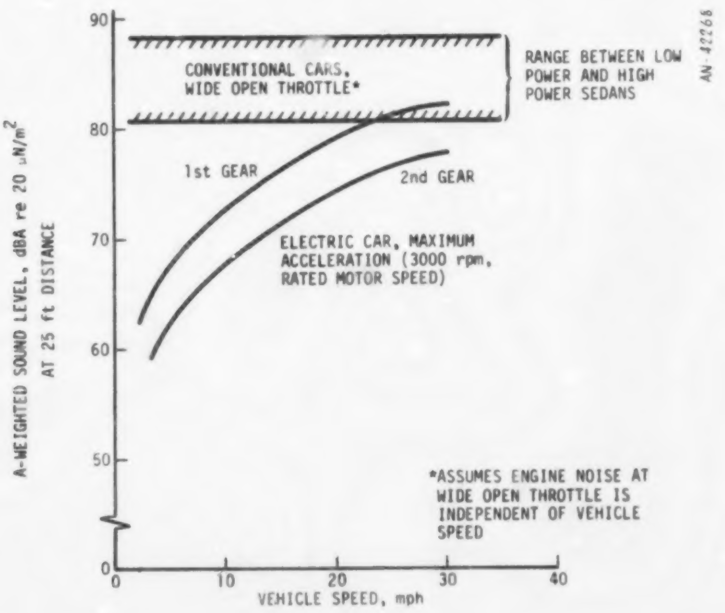

Figure 4.1. Comparison of Electric Car and Conventional Car Engine Noise (Maximum Acceleration at Low Speeds)

occur during traffic or low speed operations. Thus, according to the curves in Fig. 4.1, motor noise levels for either electric cars or conventional cars will dominate over tire-road noises (Table 4.2 indicates that tire-road noise at 35 mph for a low-power sedan is approximately 65 dBA). Expected noise quieting for installed electric car motors will further improve the comparison between the noisier conventional autos at wide open throttle and electric cars. If, for example, noise quieting should result in a 10 dBA drop in the electric car motor noise levels, motor noise under maximum acceleration conditions will continue to dominate over tire-road noises (except in the cases of very rough roads) and the electric car total noise level would be decreased proportionately. By this comparison, electric cars should aid materially in reducing the incidence of noise intrusions by accelerating automobiles.

In order to draw further comparisons of electric car noise generation with that of the conventional auto, we used the above estimating relationship to evaluate electric car noise at typical 35-mph and 65-mph cruise conditions. At 65 mph the four-passenger configuration requires about 35 hp, for which it was assumed that vehicle speed corresponds to rated motor speed. At 35 mph, required cruise power is 8 hp and motor speed is approximately 54 percent of rated speed. Table 4.3 summarizes calulations of expected A-weighted noise levels at 25-foot distances for these conditions, with rated motor speed parameterized over a range of 3,000 to 12,000 rpm. The equivalent value for the low-power sedan of Table 4.2 is presented for comparison.

At the lower speeds, expected quieting for the installed electric car motors should lower the motor noise contribution to where tire-road noise, even on smooth surfaces, dominates. Under cruise conditions the electric car will then contribute as much to urban noise as conventional low-power sedans. Only in the case of the highest electric motor speed does it appear that motor noise, allowing for quieting, may become the most significant source. If the estimating relationship is accurate in

TABLE 4.3

COMPARISON OF CONVENTIONAL AUTO AND ELECTRIC CAR MOTOR NOISE LEVELS, CRUISE CONDITIONS

dBA at 25-ft Distance re 20 μN/m^2

	35 mph		65 mph	
Rated Motor Speed, rpm*	Electric Car Without Noise Quieting	Conventional Low-Power Sedan**	Electric Car Without Noise Quieting	Conventional Low-Power Sedan**
3,000	69.9	67.5	80.3	77.7
6,000	74.4		84.8*	
12,000	78.9*		89.3*	

---

*Note that the estimating relationship was based on data for motor speeds in the range 450 to 3,600 rpm; consequently, the calculations with greater speeds must be viewed with some caution.

**Columns 1 and 6 in Table 4.2; total noise, cruise condition.

the sensitivity it accords to traction motor speed, these noise levels suggest that low rated motor speed should be selected as a design criterion. However, operation at cruise speeds on rough roads would probably increase tire-road contributions to a level that would dominate total noise generation from either type of vehicle. The estimates in Table 4.3 at high electric motor speeds must be viewed with caution since the relationship was developed from motor data that spanned the speed range 450 to 3,600 rpm. Also a comparison of predicted sound pressure levels based on the estimating relationship with actual sideline measurements of a BART car showed agreement only within 5 to 10 dB for octave-band levels over the sound spectrum.[27] Otherwise the goodness of fit of the estimating relationship is not known.

It is noteworthy to report some of the data on auto noise generation resulting from the 1972 Urban Vehicle Design Competition (UVDC).

Comparison of noise measurements taken at 25 feet sideline distance of the Cornell electric car and 35 other experimental cars employing variously fueled internal combustion engines showed the electric to be 12 dB quieter in terms of overall sound pressure level (the electric was measured at 64 dB while the average of the 35 other vehicles was 76.3 dB).[32] The measurements were taken at a cruise condition of 30 mph. These values are not directly scalable to A-weighted noise levels, since the spectral contents of the sound levels are not known and are probably quite variable over the range of experimental vehicles investigated. Nonetheless, the figures tend to indicate that electrics under cruise conditions will be significantly quieter than conventionally powered internal combustion cars.

4.3 EFFECT OF ELECTRIC CAR USE ON COMMUNITY NOISE

Based on the foregoing appraisal of likely electric car noise generation, some general observations and conclusions are offered concerning the effects wide usage of electric cars may have on community noise.

With regard to general background traffic noise, the electric car is likely to have some impact only through a reduction of the contributions arising from start-and-stop operation in traffic. Operation on surface streets with traffic regulation involves much stop and go, with corresponding accelerations and decelerations, under which conditions the electric car would be expected to be significantly quieter.

The total effect on background noise further depends on the proportion of electric cars in the vehicle population. The reduction in the contribution to background noise, on an integrated basis involving cruise and acceleration conditions, due to electrics replacing conventional cars is not large and will probably be significant only if there is a large population of electric cars. Also there may be other sources that dominate background noise levels in some instances which will remain unaffected by electric car use, e.g., significant levels of diesel truck operations in some neighborhoods. All these considerations combine to create a situation in which it is difficult to quantify the likely effect of electric cars on background community noise levels.

Within the category of traffic noise intrusions, significant sources are: motorcycles, variations in traffic flow, automobile exhaust noise, and diesel trucks. Surveys on noise annoyance factors indicate that often these intrusions are believed to be the result of improper operation of the vehicles, such as gunning engines, accelerating at high speeds, etc.[33] They tend to be much more noticeable at night and involve vehicle operations near the receiver to the extent that the noise level incident at the receiver rises 20-to-30 dB or more above the background.

Electric cars do not have the characteristics to produce noise intrusions of this sort, as indicated by the comparison shown in Fig. 4.1. However, it is difficult to speculate to what degree purchasers of electric cars would be previous owners of the type of cars generally thought to be involved in most noise intrusions. Surveys have shown that most often the annoyed person thought the source, when identified as an automobile, to be a sports car. In general, electric cars are not likely to appeal to those purchasers seeking the characteristics offered by a sports car. However, in those cases of noise intrusions from inadvertent auto operations, we would expect electric cars to have a significant effect in reducing the number of noise intrusion incidents.

4.4 ELECTRIC GENERATION POWER PLANT NOISE

A 1971 survey by the EPA[34] on noise generation from industrial plants included studies of the effect of electric power plant noise on community noise levels. The electric power plant that was surveyed employed five steam turbine generators of 100 MW capacity and one gas turbine generator. The plant was 3,000 to 4,000 feet from the nearest residential neighborhood. Noise measurements were taken at a variety of stations ranging from just outside the plant building to several places throughout the nearby neighborhood. Day and night measurements were made, and it was concluded that the power plant was not the primary source for the background noise levels measured anywhere within the nearby residential neighborhood, although it may have been a significant contributor. At the 10 percent exceedance level, the average values in the nearby community were 61 dBA during the day and 60 dBA during the night. The average background noise levels were around 53 dBA for either night or day. These values suggest a representative urban neighborhood (see Table 4.1). This conclusion held for both day and night conditions. Therefore, based on this limited sample, it is unlikely that the additional generating requirements for recharging large numbers of electric cars at night will significantly affect nearby community noise levels.

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TASK REPORT 9

PARAMETRIC ECONOMIC IMPACTS OF ELECTRIC CARS IN LOS ANGELES

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ABSTRACT

This paper estimates the economic impacts which would accrue to the Los Angeles region in the event electric cars are substituted for internal combusion engine cars. The average 1990 internal combustion car in the Los Angeles region is estimated to have a life-cycle cost of 15.5 cents a mile (in 1973 dollars). Electric car life-cycle cost per mile would range from 23 percent less to 38 percent more, depending on the type of battery employed. Reductions in regional employment opportunities would range from 0.2 to 1.2 percent, also depending on battery type.

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1 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This study presents, in parametric form, the impacts imposed on the Los Angeles economic system by electric car usage. Task Report 4 (also Ref. 1) projected the levels of economic activity for these enterprises which were considered susceptible to electric car impacts. The projections were based upon current trends without electric car usage. This study, for various levels of electric car usage, quantifies the impacts that can be expected upon those economic activities.

Section 2 develops the impacts which would accrue to transportation consumers, primarily the comparative costs of internal combustion engine automobiles and electric cars. Section 3 shows the impacts on suppliers of transportation equipment and services, discussed by level of importance. Section 4 discusses the secondary impacts, specifically, the cost changes imposed upon disposable personal income.

1.2 SUMMARY

The impacts of conversion from internal combustion engine automobiles to electric cars are shown as they affect the consumer and the Los Angeles regional economy (the California South Coast Air Basin, or SCAB, to be precise). The impact upon the consumer is shown by deriving the user life-cycle cost of the average internal combustion engine automobile (the 1973 cost of each car class adjusted for the expected market share of that class in future decades) and the comparable cost of the electric car. The impact upon the region (secondary impacts) are calculated by determining the employment shifts and payroll changes which would accrue. These are expected to result from decreased automobile servicing and increased battery manufacturing requirements. They are displayed as a percentage of expected employment and total personal income levels.

The impact of a complete conversion to electric car use was examined for each of four battery types, and, in two cases, best and worst performance levels. Both primary and secondary impacts are assumed proportional to the level of conversion. The findings for each battery type are summarized below. All costs are given in 1973 dollars.

Lead-Acid Battery: Best Performance Assumption

The user life cycle cost is 16.0 cents per mile. This is 1 percent more than the user life cycle cost of the average 1980 internal combustion engine automobile. The secondary impacts of a complete transition to electric car use are expected to reduce employment opportunities by 0.75 percent and reduce total personal income by 0.20 percent.

Lead-Acid Battery: Worst Performance Assumption

The user life cycle cost is 21.8 cents per mile. This is 37 percent more than the cost of the average 1980 internal combustion engine automobile. This is the costliest electric car option. Secondary impacts are negligible. A 100 percent substitution of electric cars would reduce area employment opportunities by 0.15 percent and increase total personal income by about the same amount.*

Nickel-Zinc Battery

The user life cycle cost is 18 cents per mile. This is 13 percent more than the user life cycle cost of the average 1990 internal combustion engine automobile. Secondary impacts include a 0.85 percent reduction in employment opportunities and a total personal income loss of 0.20 percent.

Zinc-Chlorine Battery

This is the least expensive alternative. The user life cycle cost of 11.9 cents per mile is 23 percent less than the average 1990 internal combustion engine automobile user life cycle cost. There are, however, significant secondary impacts with an employment opportunity loss of 1.2 percent and a total personal income loss of 0.35 percent.

---

*Total income increases while employment decreases because of the loss of low-salaried employees and an increase of high-salaried employees.

Lithium-Sulfur Battery: Best Performance Assumption

The user life cycle cost is 12.4 cents per mile, 19 percent less than the comparable (year-2000) internal combustion engine automobile cost. The secondary impacts are the most significant: an employment opportunity loss of 1.4 percent and total personal income reduction of 0.35 percent.

Lithium-Sulfur Battery: Worst Performance Assumption

The user life cycle cost is 13.2 cents per mile, about 14 percent less than the comparable (year-2000) internal combustion engine automobile costs. The employment opportunity loss is expected to be 1.1 percent and the total personal income loss 0.3 percent.

2 IMPACTS ON TRANSPORTATION CONSUMERS: A COMPARISON OF VEHICLE COSTS

The relative costs of electric car ownership are critical in determining their desirability to the consumer. Section 2.1 develops the comparative costs for internal combustion engine and electric cars. The cost of owning a car is a combination of factors: initial cost, finance costs, maintenance, taxes, fuel, insurance, repairs, etc. All the cost elements must be taken into consideration, along with the expected mileage, in order to have a valid basis for comparing the costs of vehicles. The following subsections 2.1 and 2.2 develop the costs for the internal combustion engine automobile and the electric car.

2.1 INTERNAL COMBUSTION ENGINE VEHICLE COSTS

These costs are largely taken from 1972 US Department of Transportation (DOT) figures on auto costs.[2] Figure 2.1 shows the assumptions that underly the data. One DOT assumption that this study changes is the price of gasoline. DOT assumed about 38 cents per gallon (including 11 cents tax). All costs other than gasoline were adjusted from 1972 to 1973 dollars using a 10 percent inflation factor. If gasoline were treated in this manner, the estimated 1973 cost would be 42 cents, unrealistic in view of recent price developments. The derivation of gasoline costs are discussed in following paragraphs.

Other additions are made to the DOT costs for pollution devices and their maintenance and for finance costs. These costs for pollution devices are taken from an EPA study which derives the additions to vehicle purchase price, given current legislative requirements for pollution control. In addition, the study estimates yearly maintenance costs for the device.[3] The DOT figures show the cost of purchase and operation. To account for total life-cycle costs to the user, the cost of financing the purchase must be included. This is important because of the variation in the amounts required for initial purchase.

Item	Standard Size Automobile	Compact Size Automobile	Subcompact Size Automobile
Automobile Description	1972 model 4-door sedan. Equipped with: V-8 engine, automatic transmission, power steering and brakes, air conditioning, tinted glass, radio, clock, white-wall tires, and body protective molding.	1972 model 2-door sedan. Equipped with: 6 cylinder engine, automatic transmission, power steering, radio, and body protective molding.	1972 model 2-door sedan. Equipped with: standard equipment plus radio and body protective molding.
Repairs and Maintenance	Includes routine maintenance such as lubrications, repacking wheel bearings, flushing cooling system, and aiming headlamps; replacement of minor parts such as spark plugs, fan belts, radiator hoses, distributor cap, fuel filter, and pollution control filters; minor repairs such as brake jobs, water pump, carburetor overhaul and universal joints; and major repairs such as a complete "valve job."		
Replacement Tires	Purchase of 7 new regular tires and 4 new snow tires during the lives of the cars was assumed.		
Accessories	Purchase of floor mats the first year, seat covers the sixth year, and miscellaneous items totaling $2.00 per year was assumed.		
Gasoline	Consumption rate of 13.60 miles per gallon was used.	Consumption rate of 15.97 miles per gallon was used.	Consumption rate of 21.43 miles per gallon was used.
Oil	Consumption was associated with gasoline consumption at a rate of 1 gallon of oil for every 186 gallons of gasoline.	Consumption was associated with gasoline consumption at a rate of 1 gallon of oil for every 166 gallons of gasoline.	Consumption was associated with gasoline consumption at a rate of 1 gallon of oil for every 135 gallons of gasoline.
Insurance	Coverage includes $50,000 combined public liability ($15,000/$30,000 bodily injury, and $5,000 property damage), $1,000 medical payments, uninsured motorist coverage, and full comprehensive coverage for the 10-year period. Deductible collision insurance was assumed for the first 5 years ($100 deductible).		
Garaging, Parking, and Tolls	Includes monthly charges of $10.00 for garage rental or indirect cost of the owners garaging facility; plus parking fee average of $54.00 per year, and toll average of $6.94 per year, both of which were assigned in proportion to annual travel.		
Taxes	Includes Federal excise taxes on tires (10 cents per pound), lubricating oil (6 cents per gallon), and gasoline (4 cents per gallon); plus the Maryland tax on gasoline (7 cents per gallon), titling tax (4 percent of retail price), and registration fee ($20.00 for 3,700 pounds or less shipping weight, or $30.00 for vehicles over 3,700 pounds).		

Figure 2.1. Automobile Operating Costs, Bases for Estimates[2]

The interest paid over the 10-year life of the car is calculated with the following standard interest formula.

$$\text{Annual Payment} = \frac{Pi(1 + i)^n}{(1 + i)^n - 1}$$

where

P = cost of car

i = 10 percent annual interest rate

n = 10-year lifetime of car

The interest rate of 10 percent is an average between the cost of borrowing money and the opportunity cost to the consumer who finances his own car. The annual payment is multiplied by n to show the total payment. When the initial purchase price is subtracted from the amount of the total payment the residual amount is the finance cost.

All costs in this section are presented as cost per mile in 1973 dollars. This allows the costs of the two vehicle types to be compared on an equal basis. Table 2.1 shows the development of the cost per mile for the internal combustion engine auto.

The cost of gasoline is subject to some uncertainty. The National Petroleum Council Study[4] examined in Ref. 5 predicts a long-term equilibrium price of $6.50 for a barrel of petroleum in 1973 dollars. This corresponded to a March 1974 level of $5.25 a barrel for controlled (domestic) oil and an average price of $10.35 for exempt (foreign) oil.[6] The weighted average price for a barrel of crude used in US gasline production was about $6 to $7. Oil company accounting principles dictate that the price of gasoline is related to the current price of crude rather than to the cost of inventory stocks. The Oil and Gas Journal noted that the March 1974 price of gasoline in Los Angeles was 47 cents per gallon.[7] Thus, assuming the price of crude is the dominant factor in gasoline price variances, the

TABLE 2.1

INTERNAL COMBUSTION ENGINE AUTOMOBILE OPERATING COST AT 10,000 MILES PER YEAR FOR 10 YEARS[*]

	Standard		Compact		Subcompact	
Costs Excluding Taxes						
Amortization	$ 4,817		$ 2,966		$ 2,270	
Pollution Device[**]	280		280		260	
Finance Costs	3,200		2,042		1,591	
Repair and Maintenance	2,362		1,963		1,953	
Maintenance of Pollution Device[**]	650		650		600	
Replacement Tires	440		376		344	
Accessories	57		57		57	
Gasoline	2,941[†]	(5,145)[††]	2,505[†]	(4,385)[††]	1,867[†]	(3,266)[††]
Oil	156	(250)	149	(239)	137	(218)
Insurance	1,485		1,429		1,376	
Garaging, Parking, Tolls, etc.	1,990		1,990		1,990	
Subtotal	18,378	(20,676)	14,407	(16,377)	12,445	(13,925)
Taxes and Fees						
State						
Gasoline	442[†]		275[†]		280[†]	
Registration	330		220		220	
Titling	195		121		93	
Federal						
Gasoline	295[†]		250[†]		186[†]	
Oil	3		3		3	
Tires	34		29		23	
Subtotal	1,299		898		805	
Total	$19,677	($21,975)	$15,305	($17,275)	$13,250	($14,730)
Cents Per Mile	19.7c	(22.0c)	15.3c	(17.3c)	13.3c	(14.7c)

---

[*] Based upon Ref. 2. All costs (except gasoline, oil and their taxes) are adjusted to 1973 dollars using a 10 percent per year inflation factor.

[**] From Ref. 9.

[†] Gasoline assumed to cost 50 cents per gallon, including 10 cents tax, in 1973 dollars; oil costs are adjusted accordingly.

[††] Gasoline assumed to cost 80 cents per gallon, including 10 cents tax, in 1973 dollars; oil costs are adjusted accordingly.

projected long-term price of gasoline (including tax) should be about 50 cents per gallon, corresponding to a long-run price of crude at $6.50.

The short-term price of gasoline is far more uncertain with politics influencing the supply of oil and with the price elasticity of demand somewhat uncertain. Various studies done at Harvard and by the Federal Energy Office have predicted a possible short run upper bound price of 75 to 80 cents per gallon.[8]

Accordingly, the internal combustion engine auto cost was computed for two levels of gasoline cost.* Operating costs are calculated for cars using gasoline at 50 and 80 cents per gallon (this includes 6 cents state and 4 cents federal gas tax). This 60 percent variance in the price of gasoline resulted in only a 12 percent variance of the per mile cost of the standard car.

Table 2.2 summarizes the cost per mile for internal combustion engine cars. The parameters of 10,000 miles a year for 10 years, while taken from the referenced DOT paper, are consistent with figures developed in Ref. 10 for Los Angeles. Table 2.2 also has an average cost per mile based on the auto population by class as projected in Ref. 10. The decreasing cost from 1980 to 1990 to 2000 is due to the increasing percentage of subcompacts (which are less expensive to operate).

In calculating fuel costs, the fuel economy figures from the referenced DOT paper were used without modification, as shown in Table 2.1. If instead the reduced fuel consumption rates projected in Ref. 10 were used, the total costs per mile (for gasoline at 50 cents per gallon) for the average car in Table 2.2 would be reduced 0.2 cents in 1990 and 0.5 cents in 2000.

---

*Oil was scaled to the price of gasoline.

TABLE 2.2

SUMMARY OF INTERNAL COMBUSTION VEHICLE OPERATING COST PER MILE AT 10,000 MILES/YEAR FOR 10 YEARS IN 1973 DOLLARS

	Cents per Mile**	Cents per Mile†
Standard	19.7	22.0
Compact	15.3	17.3
Subcompact	13.3	14.7
Weighted Average*		
1980	15.9	18.0
1990	15.5	17.5
2000	15.4	17.4

---

*Based on SCAB auto population share by class as shown in Ref. 10 with intermediate and specialty assumed to cost midway between standard and compact.

**Gas at 50 cents per gallon

†Gas at 80 cents per gallon

2.2 ELECTRIC VEHICLE COSTS

Electric vehicle costs are derived from a variety of sources and will be explained below by cost item. The cost items are similar to those in Table 2.1 with four exceptions. Battery depreciation is added to the amortization account. Batteries are a substantial recurring portion of electric car costs. The cost of electricity is substituted for gasoline and oil costs. Pollution control costs are omitted and a road use tax is retained. As before, costs are given in 1973 dollars at retail prices.

Tables 2.3 and 2.4 show the results of the electric car cost calculations. Table 2.3 shows costs based upon travel of 6,300 miles per vehicle per year because Task Report 10 shows that initial penetration of electric vehicles will be in a market characterized by lower annual mileage. DOT expected a 10-year life for the ICE car and Leeds of England and others experienced a 15-year electric vehicle life. The 12-year life span was chosen as a compromise.

TABLE 2.3

FOUR-PASSENGER ELECTRIC CAR OPERATION COST WITH THE LEAD-ACID BATTERY FOR 12 YEARS IN 1973 DOLLARS

	Best Battery Performance at 6,300 mi/yr	Worst Battery Performance at 6,300 mi/yr	Best Battery Performance at 10,000 mi/yr	Worst Battery Performance at 10,000 mi/yr
Costs Except Taxes				
Amortization				
Vehicle (without battery)	$ 2,977	$ 2,977	$ 2,977	$ 2,977
Battery and Replacements	3,592	7,518	4,200	10,982
Finance Costs	3,805	4,005	3,009	3,225
Repairs and Maintenance	755	755	1,200	1,200
Replacement Tires	325	325	527	527
Accessories	69	69	69	69
Electricity	1,134	1,134	1,800	1,800
Insurance	1,782	1,782	1,782	1,782
Parking, Tolls, etc.	2,388	2,388	2,388	2,388
Subtotal	16,827	20,953	17,952	24,950
Taxes				
State				
Registration	264	264	264	264
Title	93	93	93	93
Federal Tax on Tires	25	25	41	41
Road Use Tax[*]	525	525	850	850
Subtotal	907	907	1,248	1,248
Total	$17,734	$21,860	$19,200	$26,198
Cents Per Mile	23.5¢	28.9¢	16.0¢	21.8¢

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[*] Imposed as a surrogate for gas taxes.

TABLE 2.4

FOUR-PASSENGER ELECTRIC CAR OPERATION AT 10,000 MILES PER YEAR FOR 12 YEARS IN 1973 DOLLARS

	Nickel-Zinc Battery	Zinc-Chlorine Battery	Best Lithium-Sulfur Battery Performance	Worst Lithium-Sulfur Battery Performance
Costs, Except Taxes				
Amortization				
Vehicle (without battery)	$ 2,945	$ 2,891	$ 2,795	$ 2,795
Battery and Replacements	6,125	993	1,440	2,400
Finance Costs	4,462	2,640	2,580	2,628
Repairs and Maintenance	900	900	900	900
Replacement Tires	527	451	451	451
Accessories	69	69	69	69
Electricity	1,163	935	1,026	1,026
Insurance	1,782	1,782	1,782	1,782
Parking, Tolls, etc.	2,388	2,388	2,388	2,388
Subtotal	20,361	13,049	13,431	14,439
Taxes				
State				
Registration	264	264	264	264
Title	93	93	93	93
Federal Tax on Tires	41	34	34	34
Road Use Tax*	850	850	850	850
Subtotal	1,248	1,241	1,241	1,241
Total	$21,609	$14,290	$14,672	$15,680
Cents Per Mile	18.0¢	11.9¢	12.2¢	13.1¢

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*Imposed as a surrogate for gas taxes.

2.2.1 Amortization of Car Cost

The initial cost of the vehicle is calculated using data from a Ford Motor Company report, Electric Vehicle System Study.[12] This report was utilized because it was the only report available which estimates costs and prices of electric vehicle systems for a large quantity of units. The following 1973 price data for a 45-hp electric car was derived from the Ford report:

Basic Car (without battery)	$1,880
Motor and DC Chopper	$ 725

That electric car weighs 2,067 pounds (exclusive of batteries, motor, and chopper) and thus the basic car (without batteries, motor, and chopper) costs 91 cents per pound.

This cost figure of 91 cents per pound was applied to the four-passenger electric car of this study to derive costs of $2,252, $2,220, $2,165, and $2,070 (exclusive of batteries, motor, and chopper) for the basic lead-acid, nickel-zinc, zinc-chlorine, and lithium-sulfur cars, respectively. It is reasonable that the basic car cost should vary with battery weight as the car requires less structural material to support a lesser battery weight. To this basic cost was added $725 for motor and chopper. The rationale underlying this was that the drive train for the four different cars would reflect weight to some degree but that the cost of the rest of the car would vary with the weight.

2.2.2 Amortization of Battery Cost

The cost of the lead-acid battery requirements for the vehicle lifetime is calculated using the battery performance cruves in Task Report 13. The curves show best and poorest battery life in years as a function of available range used. Maximum range is listed as 54 miles based upon the SAE metropolitan driving cycle. Percent utilization is calculated by dividing average daily mileage by 54. The curve gave the following battery life figures:

At 6,300 miles per year:
  Best: 4.0 years
  Poorest: 1.9 years

At 10,000 miles per year:
  Best: 3.4 years
  Poorest: 1.3 years

The total battery cost was then calculated for 12 years using 80 cents per pound (or $1,200) for each pack. This figure was derived from current SLI lead-acid battery retail prices.

The price of the lead-acid battery assumes the turn-in of a battery of the same size. The valuation of this turn-in is usually about 10 percent of the replacement lead-acid battery cost. Since the initial purchaser of an electric vehicle will have no batteries to turn in, a one-time assessment will probably be required. If this assessment amounts to 10 percent of the cost of the first lead-acid battery pack, it would add $120 (or 0.1 cents per mile) to the cost of the vehicle.

Conversely, the cost of the other three electric car battery types do not include a turn-in allowance, since the assignment of some turn-in value is based upon many uncertain variables (e.g., demand and cost of handling and refining) not yet available. This omission is probably most critical in the nickel-zinc battery, where both the cost and quantity of the recyclable raw materials and the cost of the battery are high. Assuming some upper limit of turn-in value, say 25 percent of purchase price, and applying this factor to the purchase of the second and succeeding battery packs, it is possible to reduce the vehicle cost per mile by 1.0 cents. A more likely turn-in value is about 10 to 15 percent, which would, of course, have a lesser impact on per-mile costs.

Table 2.4 shows the most likely costs for the future batteries. An original Ni-Zn battery cost of $2940 is estimated using data from Task Report 1 showing a cost of $60 per KWH and a 49 KWH capacity. Assuming

400 deep discharge cycles and a 144-mile range, the mileage available from the battery is 57,600 miles.* The $2,940 cost is then adjusted for a 12-year, 10,000-mile-per-year car. The zinc-chlorine battery is estimated to cost $600 and have a capacity of 500 deep discharge cycles and a range of 145 miles. Thus the mileage available is 72,500 miles and the cost is adjusted upward to provide 120,000 miles of total battery life.

The battery costs for the lithium-sulfur battery are more easily calculated. In Task Report 1 it is estimated that the battery will have a life of 3 to 5 years. The constraint here is years rather than cycles as total hot life is estimated to be the lifetime determinant. The lithium-sulfur battery is assumed to last from 3 to 5 years. The cost per pound is estimated in Task Report 1 to be $2, or $600 for the pack, once sufficient production levels are achieved.**

2.2.3 Finance Costs

The finance costs for the electric car (without battery) is derived using the same formula used in deriving ICE car finance costs. The time period (n) is 12 years rather than 10, however. The calculations used to derive the finance cost of the battery are based upon the same formula but the time period (n) is the expected lifetime of the battery rather than of the car. The finance cost for one battery is converted to a mileage cost based upon the expected lifetime of the battery. Finance costs are derived by applying these mileage costs to the total number of miles expected over the lifetime of the car.

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*Obviously, 144 miles is more than the average 29 miles per day which would be driven to accumulate 10,000 miles a year. However, at less than 144 miles the battery discharge would be proportionately shallower and more discharges would be obtained during the life of the battery.

**All battery cost factors are based upon production levels sufficient to obtain economics of learning and of scale.

2.2.4 Repairs and Maintenance

When compared to the internal combustion engine vehicle, the electric vehicle is projected to require fewer repairs and maintenance actions. The engine, with all its encumbrances, is replaced by an electric motor, batteries, and controls. Repair and maintenance costs for the electric car are estimated on a per mile basis using data from the same Ford report,[12] from DOT costs, and from maintenance data in Sec. 3.2 which develops the percentage of repair activity that is directly related to the internal combustion engine.

The total cost is 1.0 cents per mile for the lead-acid battery car and 0.75 cents for all other battery types. This is allocated on the basis of 0.2 cents per mile for motor, commutator, and controls, 0.25 cents per mile for lead-acid battery maintenance, and 0.55 cents per mile for all other maintenance. The 0.55 cents figure was derived from the DOT maintenance figures, through application of the factor developed in Sec. 3.2 showing that 28 percent of vehicle repairs are germane to the basic vehicle (mostly tire and suspension related) rather than to the internal combustion engine propulsion system. This percentage is applied to the DOT maintenance cost figure of 1.9 cents per mile to derive the electric car general maintenance cost of 0.55 cents per mile.

At 10,000 miles a year, this is $20 per year for maintenance and parts for the motor, commutator and controls, $25 per year for lead-acid battery maintenance, and $55 per year for basic car maintenance. The brushes in the electric motor should be checked about once every year and replaced if excessive wear is indicated. This is a relatively minor task and should require no more than a half hour of labor. The controls are all electric and should not require any maintenance, though it should be inspected occasionally. Twenty dollars a year should be adequate for this activity. Lead-acid battery maintenance consists of adding water to the cells and cleaning the terminals. The $25 allows ten checkups a year, assuming that the 72 or so cells can be checked and the terminals cleaned in half an hour at $5 an hour.[*] A lower hourly rate is used here as it is assumed this work can be done by lesser skilled service station attendants. The $55 would go for other miscellaneous general maintenance such as lubrication of the suspension, alignment and balancing of the tires, brakes, light adjustment, body repair, transmission, shocks, and steering.

The other battery types are not expected to have sufficient maintenance requirements to justify any cost. The nickel-zinc battery will require only the semi-annual addition of some liquid. Energy Development Associates is designing their zinc-chlorine battery so that maintenance requires only the infrequent changing of cannisters designed to trap exit gases and add electrolytes. They predict that this can be done simply by the vehicle operator every 2 to 3 months. The lithium-sulfur battery must be maintained at 300°C-400°C (internal temperature) and no battery maintenance is possible as a drop to any temperature where repairs could be enacted would permanently disable the battery.

2.2.5 Replacement Tires and Accessories

Replacement tires are costed on a per-mile basis using the DOT figures for the internal combustion engine vehicle. The replacement tire cost for the lead-acid battery car at 10,000 miles a year for 12 years is 1.2 times the tire cost for the standard car (chosen because of the weight similarity to the lead-acid car), while the cost for the lead-acid battery car used only 6,300 miles a year is 0.75 times the DOT standard car tire costs. The zinc-chlorine and lithium-sulfur battery car tire replacement cost is 1.2 times the compact car tire cost. Since accessories were accrued on a yearly basis, their cost is simply 1.2 times the DOT cost for subcompact accessories.

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[*] Labor-saving devices, such as a filler which requires the addition of water in only one orifice, are being developed but are still 3 to 6 years from production. A maintenance-free battery with high frequency discharge capability is also in the development stages but is 5 to 10 years from production. The nickel-zinc battery will require the addition of liquid to only one orifice.

2.2.6 Electricity

Task Report 1 predicts that the four-passenger lead-acid vehicle will require 0.79 KWH per mile; the nickel-zinc, 0.51 KWH per mile; the zinc-chlorine, 0.41 KWH per mile; and the lithium-sulfur vehicle will travel 0.45 KWH per mile. This estimate accounts for the inefficiencies of the mechanical components, motor, batteries, and charger, so this is an estimate of demand at the meter. Accessories have been assumed to be zero for the electric car in the SCAB.

Electric rates are structured so that beyond certain increments of electricity used, the marginal rate is less than the average rate. That is, the more electricity consumed, the lower the cost per KWH. According to the Edison Electric Institute, average residential use in 1972 was 640 KWH a month. A lead-acid electric car getting 0.79 KWH per mile uses about 660 KWH per month. Cars using the other battery types require from 340 to 425 KWH per month. In 1973, PG&E charged residential users 1.9 cents per KWH between 600 and 1200 KWH. Most KWHs demanded for electric car use will fall into a range of the rate structure where power demanded is priced at 1.9 cents per KWH. The cost for electricity is then 1.5 cents per mile for the lead-acid battery car, 0.97 cents per mile for the nickel-zinc battery car, 0.78 cents per mile for the zinc-chlorine battery car, and 0.86 cents per mile for the lithium-sulfur battery car.

2.2.7 Insurance, Parking, and Taxes

The cost of insurance, state registration, garaging, parking, tolls, etc., are those DOT cost categories adjusted for the difference in years of operation. Insurance costs, as well as state title cost, is based on the DOT subcompact costs to reflect the lower rates accruing to smaller cars. To calculate the tire tax, the DOT tire tax rate is applied to the electric car tire costs.

2.2.8 Road Use Tax

Historically, the costs of roadways have been borne by the user through gas tax revenues. If electric vehicles are implemented, that mode of allocating costs will no longer be possible. We assume that the public policy of user-borne costs will continue and accordingly have added a road use tax to the cost of the electric car. This cost was calculated using the rate of 10 cents per gallon (6 cents state, 4 cents federal) given the figures for average gas mileage and auto class as a percent of auto population derived in Ref. 10. This is calculated as $71 per year for the 1980 car driving 10,000 miles per year at an average of 14.1 miles per gallon.

Figures 2.2, 2.3 and 2.4 show the cost of the electric vehicles as a function of mileage. Also plotted on the curves are the projected costs for the internal combustion engine car for a 10-year life at 10,000 miles per year. The one upward-bending curve in Fig. 2.2 is a result of rapidly decreasing battery life as mileage and depth of discharge are increased.

The percent change of life-cycle costs shown in Table 2.5 are based upon costs from Tables 2.2 through 2.4. The percent impact of conversion to subcompact internal combustion engine cars is included because it is expected that conversion to electric cars will initially be in that car class. The percent change to the average internal combustion engine car shows the average impact should total conversion occur. In summary, the consumer who uses an electric car would spend from 25 percent less (zinc-chlorine battery at 11.4 cents per mile) to 37 percent more (worst lead-acid at 21.8 cents per mile) on his personal outlays for autos and auto-related items.

For the past 10 years, the amount spent on autos and auto-related items has averaged a fairly constant 12.4 percent of total personal expenditures.[14] Assuming elasticity of demand for private transportation is zero, that is, a change in the price does not change the quantity

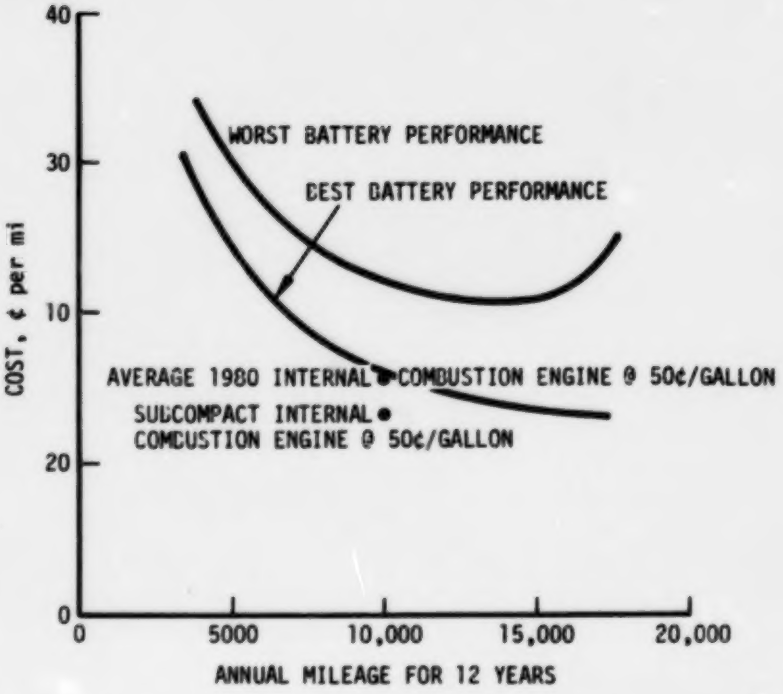

Figure 2.2. Lead-Acid Battery Car Costs

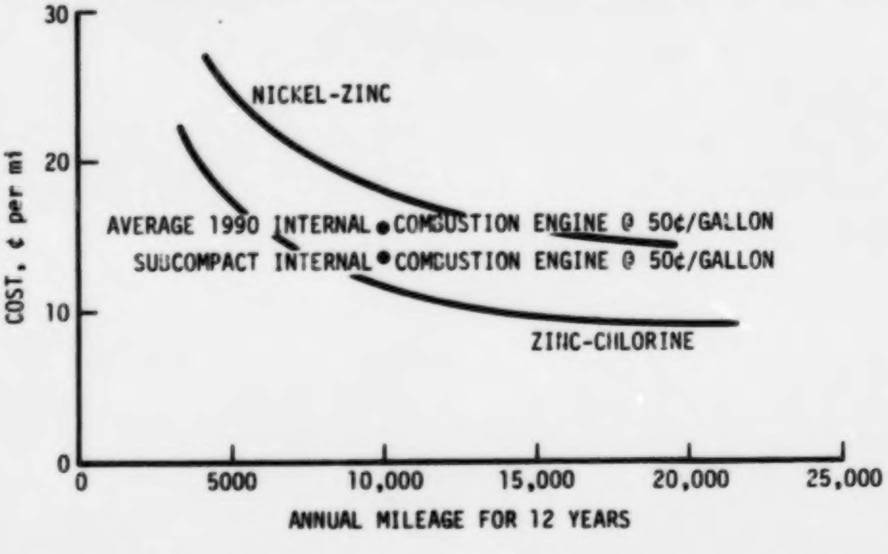

Figure 2.3. Nickel-Zinc and Zinc-Chlorine Battery Car Costs

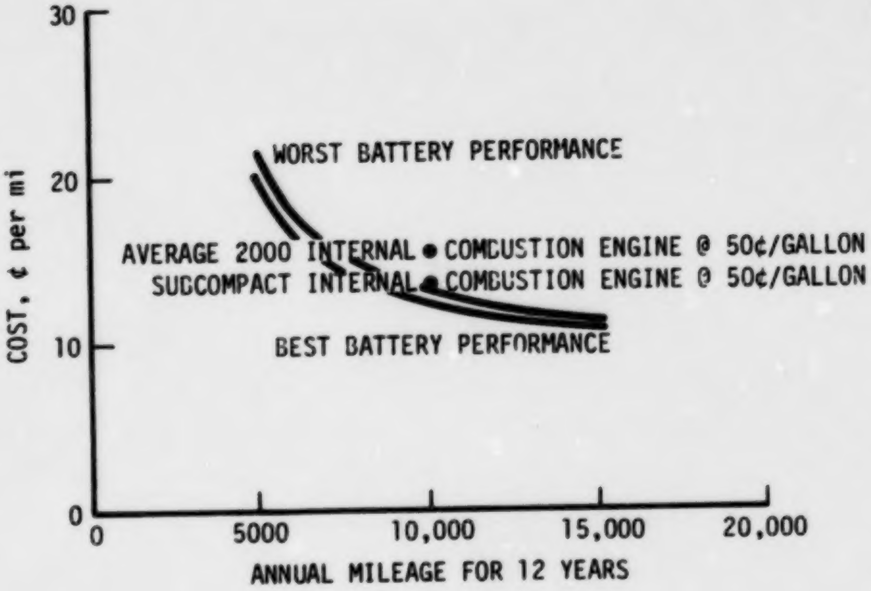

Figure 2.4. Lithium-Sulfur Battery Car Costs

TABLE 2.5

SUMMARY OF LIFE-CYCLE COSTS[*]

Subcompact Internal Combustion Engine Car (1973)		13.3¢	
Average Internal Combustion Engine Car (1980)			15.9¢
Lead-Acid Battery Car			
Best Performance	16.0¢		
Percent Change		20%	1%
Worst Performance	21.8¢		
Percent Change		63%	37%
Average Internal Combustion Engine Car (1990)			15.5¢
Nickel-Zinc Battery Car	18.0¢		
Percent Change		35%	13%
Zinc-Chlorine Battery Car	11.9¢		
Percent Change		-11%	-25%
Average Internal Combustion Engine Car (2000)			15.4¢
Lithium-Sulfur Battery Car			
Best Performance	12.2¢		
Percent Change		- 8%	-21%
Worst Performance	13.1¢		
Percent Change		- 2%	-15%

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[*] All costs given in 1973 cents per mile over the expected lifetime of the car.

demanded, the substitution of electric cars would adjust this expenditure by the percentage change in operating costs. That is, the percentage of personal outlays spent on autos could increase 37 to 17.1 percent of total personal expenditures with the worst lead-acid battery car or decrease 26 to 9.3 percent of total personal expenditures with the zinc-chlorine battery car.

3 IMPACTS ON TRANSPORTATION SUPPLIES AND SERVICES

This section discusses the variations in demand for goods and services induced by electric car usage. Task Report 4 identified the industry sectors that were susceptible to the impacts of changing demands placed upon the system by the manufacture and use of electric cars. This section presents the sectors by level of impact (major, moderate, or minor) and then identifies the nature and level of the impacts.

3.1 MAJOR IMPACTS

Two sectors are identified as sustaining major impacts. These are battery manufacturing, and petroleum distribution. The impacts on each of these are discussed below.

3.1.1 Battery Manufacturing

Starting, lighting, and ignition (SLI)* battery manufacturing is characterized by a half-dozen major firms and numerous smaller ones. The manufacturing units themselves are small and close to their market. This situation results because (1) SLI battery products are fairly homogeneous; that is, the products and manufacturing processes are similar for most brands, (2) there are no significant economies of scale beyond production of 1,000-2,000 units a day,** and (3) it is easier to transport lead than the finished battery. Due to similarities between the SLI lead-acid battery and the electric vehicle lead-acid battery, it is reasonable to predict that electric vehicle battery manufacturing requirements will be met by an increased number of manufacturing units within the area.

To calculate the extent of the impact in the South Coast Air Basin, the number and lifetime of batteries required are computed. The average weight of the two lead-acid electric-vehicle batteries (Delco and ESB) considered in Task Report 1 is 57 pounds, thus a vehicle requiring 1,500 pounds of battery would require the equivalent of 26 of these batteries. Due to the homogeneity and automation of the lead-acid battery manufacturing, and the similarity of the SLI and electric-vehicle batteries, the manufacture of electric-vehicle batteries should require about the same capital investment and labor per unit as the SLI battery.

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*This type of lead-acid battery is used in the internal combustion engine automobile.

**Telephone discussions with representatives at the Lead Industry Association and ESB Corporation.

These requirements are estimated by the industry spokesmen to be $1 million and 75 employees for a capacity of the equivalent of 1,000 SLI batteries per day. These amounts scale directly with production increases.

The lifetime is estimated in Sec. 2 to range from 1.3 to 3.4 years, while a SLI lead-acid battery lasts about 3 years. Assuming 250 working days a year, 250,000 SLI batteries are produced by each 75 employees. The gross impact in Table 3.1 shows the employees who would be displaced if SLI batteries were no longer produced. This is not equal to the employment in battery manufacturing (SIC 3691) as this category includes manufacturing of all types of storage batteries. With the equivalent of 26 SLI batteries required for each car, from 23 to 60 times as many batteries are required yearly for each electric car, varying with the expected life of the batteries. Table 3.1 gives the impacts on economic activity in battery manufacturing assuming 100 percent substitution of electric cars for internal combustion engine cars. The increase from the baseline is linear for lead-acid batteries and any intermediate impact levels can easily be determined. Using the same methodology, the increased requirements for capital are computed to range from $175 to $475 million, the range again varying with battery life assumptions. This compares to a current investment of about $8 million in battery manufacturing in the SCAB.

The requirements of the other three battery types (nickel-zinc, zinc-chlorine, and lithium-sulfur) examined in this paper are also presented in Table 3.1. They are treated in the same manner; their production

TABLE 3.1

IMPACTS ON BATTERY MANUFACTURING (SIC 3691) WITH 100 PERCENT ELECTRIC CAR USAGE IN THE SCAB

	1980		1990		2000	
	Employment	Payroll*	Employment	Payroll*	Employment	Payroll*
Baseline	2,235	24,100	2,895	34,300	3,800	45,600
Gross Impact from the Loss of SLI Battery Requirements	-588	-6,340	-673	-7,974	-760	-9,120
Requirements for Best Lead-Acid Battery	13,510	145,678	15,447	183,016	17,439	209,268
Requirements for Worst Lead-Acid Battery	35,336	381,028	40,401	478,672	45,609	547,308
Requirements for Nickel-Zinc Battery			21,310	252,481	23,752	285,027
Requirements for Zinc-Chlorine Battery			7,244	85,827	8,178	98,136
Requirements for Best Lithium-Sulfur Battery					5,929	71,148
Requirements for Worst Lithium-Sulfur Battery					9,853	118,236

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*Thousands of dollars

requirements are related to the known requirements for lead-acid batteries so the requirement may be related to existing levels.

In Table 3.1, the gross impact indicates the level of activity which will be lost due to the displacement of internal combustion engine cars. The requirements for each of the battery types indicates the level of activity required after full implementation of electric cars using that battery type. The net impact (the absolute change in employment) is simply the requirements less the gross impact.

The three other battery types under consideration have not been developed, much less produced in any quantity. Since there is little published data on the manufacturing process, representatives of the developer of each of the battery types were contacted in order to obtain some projections relating the manufacturing requirements to the lead-acid battery.

As was the case with the lead-acid battery, only 100 percent substitution of electric cars in the SCAB is shown in Table 3.1; however, requirements for various levels can be readily interpolated. The table shows the change relative to the baseline condition (i.e., internal combustion engine cars). If between some time frames there is a switch of battery types, the change can be determined simply by taking the difference in requirements for the two battery types in the latest time period. For example, if there is a change from the best lead-acid battery to the nickel-zinc battery from 1990 to 2000, there are potentially 6,313 more manufacturing jobs in 2000. Since linearity is assumed (past 5 percent), an equal mix of the two battery types would halve the potential job gains.

The change in impacts is probably not linear until about 1 to 5 percent market penetration has occurred. This is because, as opposed to lead-acid battery manufacturing, the processes are proprietary, vary from company to company, and the companies developing these batteries are located in the Eastern US. Thus it is likely that, unless the SCAB is the first major battery market, initial plant development will be elsewhere with plants being developed in Los Angeles only after the market is sizeable. It is unlikely that manufacturing would continue elsewhere after the Los Angeles market is developed for the same reasons that lead-acid batteries are manufactured locally. It is easier and less costly to transport the materials than the batteries. Gould estimates that they would build a plant with a moderate production capacity after slight market penetration in the area.

Gould estimates that the nickel-zinc battery they are developing will sustain a wage bill of about $10 per KWH. When adjusted for estimated overhead rates this equates to a payroll of $430 a battery pack or $75 a year per car (assuming a battery life of 57,000 miles). This figure is applied to the expected auto population and adjusted by the expected industry salary to derive the employment requirements shown in Table 3.1.* Energy Research estimates that each manufacturing unit will have a larger capacity and greater capital requirements than lead-acid manufacturing units. This indicates a minimum capital investment of $90 million with 100 percent substitution in the SCAB.

The zinc-chlorine battery undergoing development by Energy Development is expected to require half the labor per KWH of the lead-acid battery. Since the KWH capacity of the zinc-chlorine car is about twice that of the lead-acid car, the battery manufacturing requirements per battery pack are the same. The requirements for the lead-acid battery are merely adjusted for frequency of battery replacement to derive the zinc-chlorine battery manufacturing requirements.

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*Energy Research, another developer of the nickel-zinc battery, estimates their requirements as being about equal to lead-acid requirements per KWH. Adjusting for KWH capacity and frequency of replacement, their manpower requirements would be the same as those for best lead-acid battery.

Energy Development estimates that a production line with the capacity for 1,600 zinc-chlorine batteries a day will require abour $1.4 million. This is about 10 percent less per battery than lead-acid manufacturing requirements. Thus, assuming replacement of the battery pack every 7.2 years, the capital investment requirements for 100 percent substitution in the SCAB would be about $75 million dollars. This is less than the other alternatives as the developer plans to maximize utilization of already available "off-the shelf" items (e.g., the pumps and refrigerator) easily obtained and assembled. This will have some third-order impacts; however, it is not clear that these will be felt in LA, as those items are already produced throughout the country and are easily transported.

The lithium-sulfur battery is expected to require about 2.5 times more labor per pound than the lead-acid battery. Since the lithium-sulfur battery pack is 1/5 the weight of the lead-acid battery pack, each pack will require 1/2 the employment. The requirements depicted in Table 3.1 are adjusted to account for this and for an expected lifetime of 3 to 5 years. The manufacturing process is expected to be more costly, but is still too uncertain to be the basis for any capital requirement estimates.

There is no lead mining or refining in the SCAB. Thus there is no impact in the SCAB, nor is there likely to be as there are no known lead reserves. There is some potential for increased employment requirements nationwide. As indicated in Task Report 4, about 13,000 persons are employed nationally in these activities. Another in this series of reports indicates that if the utilization of the lead-acid battery in LA reaches 100 percent, the requirements for lead will be about four times the otherwise projected demand for all lead used in the US.[15] This increase is less than the projected increase in battery manufacturing requirements because of the use of recycled lead and the assumed lessened use of leaded gasoline.

3.1.2 Petroleum Distribution

The impacts on service stations and wholesale petroleum distributors have been topics of concern in dealing with the impacts of electric cars. This employment comprises 1.3 percent of the region's total employment and 4.1 percent of its business units. Since these businesses primarily sell gasoline, they are very susceptible to any reduction in the number of gasoline engine cars. Table 3.2 summarizes the findings of this section.

The impacts on petroleum distribution are calculated by computing the percentage of total fuel consumption dependent on automobiles. Of the 92 billion gallons of fuel consumed for highway use in California in 1970, 71 percent was for automobiles.[16] The remaining 29 percent was for motorcycles, trucks, buses, and other commercial uses. We assume that replacement by electric cars would reduce the volume of business of petroleum distributors by 71 percent and that employment would be reduced by a corresponding amount.

Linearity of impact is again assumed. Thus for some level of electric car use less than 100 percent, the negative impact or the added requirements can be adjusted by the percentage use. Linearity is assumed because of the large number of small homogeneous units (service stations) which would be affected. If there were a small number of large firms, there would be some discontinuous or non-linear impacts. With the average service station accounting for about 0.015 percent of the market, each significant change in the market can bring about a change in the number of stations and employees.

As with previous tables, the change from lead-acid to other batteries can be found by taking the difference between the total projected activity of lead-acid batteries and of the other batteries in the latest time period.

The impacts here are the same for all battery types except for some additional maintenance manpower requirements imposed by the use of the lead-acid battery.

TABLE 3.2

IMPACTS ON PETROLEUM DISTRIBUTION (SIC 5092 and 5541) WITH 100 PERCENT ELECTRIC CAR USAGE IN THE SCAB

	1980		1990		2000	
	Employment	Payroll**	Employment	Payroll**	Employment	Payroll**
Petroleum Distribution Baseline	3,646	45,300	3,366	57,900	3,420	64,600
Net Impact Petroleum Distribution	-2,589	-32,163	-2,390	-41,109	-2,428	-45,866
Projected Activity Petroleum Distribution	1,057	13,137	976	16,789	992	18,734
Service Station Baseline	39,400	182,300	43,090	208,700	46,360	237,100
Net Impact Service Stations	-35,775	-165,528	-39,126	-189,500	-42,095	-215,287
Projected Activity Service Stations	3,625	16,771	3,964	19,200	4,265	21,813
Total Projected Activity	4,682	29,908	4,940	35,989	5,257	40,547
Percent Loss	89	87	89	87	89	87
Electric Vehicle Requirements for Service Stations*	7,941	36,742	9,060	43,881	10,228	52,310
Net Impacts Service Stations*	-27,834	-128,786	-30,066	-145,619	-31,867	-162,477
Projected Activity Service Stations*	11,566	53,514	13,024	63,081	14,493	74,223
Percent Loss*	71	71	69	69	67	67
Total Projected Activity*	12,623	66,651	14,000	79,870	15,485	92,957
Percent Loss*	71	71	70	70	69	69

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*Lead-acid only.

**Thousands of dollars.

The row "Electric Car Requirements for Service Stations" (lead-acid only) in Table 3.2 is derived from an increase in two service areas required for lead-acid battery car operation. The first is battery maintenance. As explained in Sec. 2, there are no significant manpower requirements for maintenance of other batteries. Lead-acid battery maintenance is estimated to take 5 hours a year (see Sec. 2) so that at 2,000 hours a year one man could service 400 vehicles. This manpower requirement is adjusted based on the assumption that 50 percent of electric car owners would perform their own battery maintenance.* While there is no data to support this assumption, it seems reasonable in view of the relatively simple activity required. In addition, most SLI battery maintenance is now performed in conjunction with internal combustion engine tune-ups. Since this activity will be eliminated, battery maintenance would require a special stop at the service station, a less likely occurrence. In addition, service station business will probably increase by an additional 1.5 percent over other electric vehicle battery types, as the expected frequency of electric vehicle battery sales is about four times greater for lead-acid batteries than for other batteries. As explained below, other electric vehicle batteries account for 0.5 percent of service station business.

The impacts upon service stations is derived from a summary of service station sales ratios.[17] These figures are for the SCAB area service stations who buy bookkeeping and management services from E. K. Williams and Company. Stations who buy this service include almost all company-owned stations (about 80 percent of all stations are company owned) and many independent stations. The data in Table 3.3 shows the percentage breakout of the dollar value of sales (including sales of labor).

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*No similar reduction is made in the maintenance cost, as the operation is a real cost to the consumer whether he has the work done or does the work personally.

TABLE 3.3

SERVICE STATION SALES

	Percent of Total Value of Sales	Electric Vehicle Related
Gas and Oil	82.2	---
Accessories	7.9	3.0
Labor	4.4	1.2
Tires	2.9	2.9
Batteries	1.0	0.5
Other	0.9	0.9
Lubrication	0.7	0.7
	100%	9.2%

The percentage of electric-car-related sales is 9.2 percent, shown in the right-hand column. This is derived by eliminating the sales which would disappear with the introduction of electric cars. It is assumed that the amount of labor required is proportional to the value of goods and services provided. The amount of accessories sales which are dependent on internal combustion engines and thus eliminated is 62 percent, excluding tires and batteries. The derivation of this value is discussed in Sec. 3.2. Also discussed there is the basis for reducing repair-oriented labor sales by 72 percent to account for the elimination of internal combustion engines. The reduction of battery sales from 1.0 to 0.5 percent is based on the fact that the three longer range electric vehicle batteries have a lifetime about twice that of SLI batteries. While the electric vehicle batteries would be more expensive and increase the percentage of sales devoted to batteries, we are concerned with the

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*Adjustments for greater lead-acid battery sales requirements due to higher frequency of replacement were made previously.

number of persons who are supported by this activity. Even if the battery is more expensive, the number of sales persons varies more with the number of sales. Further rationale for this is presented in Sec. 3.2.

3.2 MODERATE IMPACTS[*]

The focus in this subsection is on the economic impact of electric cars on the automotive "aftermarket" and the entire automotive service industry in the South Coast Air Basin. The aftermarket includes sales of tires,[**] batteries and accessories (TBA), as well as wholesale/retail sales of replacement parts. The baseline projection for total employment in these industry sectors (SIC 5013 and 5531) for the year 1980 is 24,109; for 1990, 29,017; and for 2000, 33,972.[†] The projection for the automotive service industry and specifically auto repair shops (SIC 7538 and 7539) for 1980 is 10,584; for 1990, 12,793; and for 2000, 15,200. This represents 25 percent of area employment in auto-related activity and 0.8 percent of total employment.

In order to assess the magnitude of electric car impact on the automotive aftermarket in terms of total sales, number of firms in the industry, and total employment, we must determine what percentage of automotive business or "lines" are directly related to the internal combustion engine, which are relatively independent of type of engine or motor and which lines would be introduced or expanded in the advent of a significant electric car population.

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[*] The analysis in this section is based on total annual sales of automotive lines, frequency of repair data, estimated labor time for repairs and adjusted recommended maintenance figures. The relative percentages of internal-combustion-engine-related and non-internal-combustion-engine-related sales and repairs derived here were applied to the DOT estimated cost per mile figures in Sec. 2. The nature of the data utilized in this section precludes arriving at maintenance cost per mile estimates; however, the relative percentages derived are considered compatible with existing DOT estimates.

[**] Wholesale Tire Distribution (SIC 5014) and Tire Retreading Shops (SIC 7534) will be examined in Sec. 3.3 under Minor Impacts.

[†] The employment projections are detailed in Tables 4.5, 4.6, and 4.7 of Task Report 4.

An evaluation of the breakdown of both the automobile aftermarket and of auto service and repair is aided by the following definition:*

- Tune-up and ignition includes spark plugs, points, rotor and condensers, distributor caps, spark plug wires, and ignition coils.
- Cooling system includes belts, hoses and clamps, thermostats and gaskets, radiator caps, anti-freeze chemicals and pumps.
- Filter service includes air, oil and fuel filters, transmission filters, PCV valves and charcoal cannister elements.
- Battery/Starting/Charging system includes batteries, cables and terminals, starter motors, generators, alternators and voltage regulators.
- Tires and wheels includes tires, tire valves, snow tire studs, tire truing, O.E.-type replacement wheels, custom wheels, wheel balance and wheel alignment.
- Brake system includes shoes and pads, wheel cylinders and kits, spring kits, disc and drum machinery, master cylinders and fluid.
- Steering and suspension includes shock absorbers, ball joints, idler arms, pitman arms, wheel bearings and grease seals.
- Exhaust system includes exhaust pipes, mufflers, tail pipes, brackets and gaskets.
- Fuel system includes gasoline tanks, tank straps, vent pipes and hoses, gasoline gauges, fuel pumps, and carburetors.
- Transmission includes bushings, rods and seals, springs, gaskets, bearings, transmission assemblies, shift rods, automatic transmission assemblies, pipes and valve body assemblies.

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*This definition is consistent with the repair and maintenance items found in the DOT Repair and Maintenance category (Fig. 2.1) used in Sec. 2.

- Body and paint includes cowl and dash assemblies, hardware, paints, and body panels.
- Engine includes pistons and piston rings, valves, valve springs, short block, cylinder head gasket, and bearings.

The dollar value and percent of the market of individual sales items in the US automotive aftermarket for 1972 is shown in Table 3.4. Utilizing the percentages from Table 3.4, we attempt a further breakdown of automotive lines into those which are directly related to the internal combustion engine and those for which future consumer demand would presumably be unaffected even at maximum utilization of electric cars. The breakdown detailed in Table 3.5 was defined by assessing relative dependence of each line on the conventional internal combustion engine. In cases where there was no clearcut division, an approximate percentage was estimated in consultation with those knowledgeable in the automotive field. From this breakdown, we conclude that 44 percent of total sales of automotive lines are directly related to the internal combustion engine. The remaining 56 percent will be unaffected by changes in the means of powering the car.

Before discussing the implications of these observations on total employment and number of firms in the industry, a similar analysis of the auto repair industry will enable us to consider the impacts on both sectors simultaneously since the similarities are apparent.

Table 3.6 details the most frequently encountered automobile repairs performed by independent garages, service stations, car dealers, and those repairs done by car owners themselves. Due to the lack of readily available data on auto repair, as pointed out by the reluctant response to

TABLE 3.4

US RETAIL SALES OF AUTOMOTIVE LINES FOR 1972

Line	Sales	Percent of Total Sales
Tires	$4,700,000,000	33.2
Batteries	1,210,000,000	8.6
Spark Plugs	840,000,000	5.9
Mufflers, Pipes, etc.	774,000,000	5.5
Filters (All Types)	618,000,000	4.6
Chemicals	609,000,000	4.3
Brake Lining and Lined Shoes	527,000,000	3.7
Shock Absorbers	420,000,000	3.0
Ignition Parts	403,000,000	2.8
Fan Belts, Radiator and Heater Hose	346,000,000	2.4
Paint and Body Supplies	288,000,000	2.0
Remanufactured Units	264,000,000	1.9
Motor and Chassis Parts	214,000,000	1.5
Anti-Freeze/Coolant	206,000,000	1.5
Gasket and Oil Seals	156,000,000	1.1
Clutch Assemblies, Parts, etc.	148,000,000	1.0
Brake Parts	140,000,000	1.0
Front End Parts	132,000,000	0.9
Engines (Small) and Parts	130,000,000	0.9
Wipers and Blades	124,000,000	0.9
Equipment (All Types)	121,000,000	0.9
Lamp Bulbs, Flashers and Sealed Beams	115,000,000	0.8
Bearings (Anti-Friction)	107,000,000	0.8
Tools (Small Hand)	106,000,000	0.8
Wire and Cable Products	99,000,000	0.7
Grease and Oil	91,000,000	0.6
Carburetors and Parts	82,000,000	0.6
Bearings (Motor)	81,000,000	0.6
Fuel Pump and Parts	80,000,000	0.6
Piston Rings	75,000,000	0.5
Thermostats	68,000,000	0.5
Brass Fittings and Fuel Lines	46,000,000	0.3
Wheels and Rims	44,000,000	0.3
Tools (Power)	42,000,000	0.3
Automatic Transmission and Parts	41,000,000	0.3
All Other Lines	698,000,000	4.9
Total	$14,145,000,000	99.6*

SOURCE: Motor Age, January 1974, p. 40-45.

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*Does not add to 100% due to rounding error.

TABLE 3.5

TOP SELLING AUTOMOTIVE LINES

Lines Related to Internal Combustion Engines	Percent Share of Market	Lines Not Related to Internal Combustion Engines	Percent Share of Market
Batteries*	8.6	Tires	33.2
Spark Plugs	5.9	Chemicals (50%)	2.15
Mufflers, Pipes, etc.	5.5	Brake Lining and Lined Shoes	3.7
Filters	4.3	Shock Absorbers	3.0
Chemicals (50%)	2.15	Paint and Body Supplies	2.0
Ignition Parts	2.8	Chassis Parts	0.7
Fan Belts, Radiator and Heater Hose	2.4	Gasket and Oil Seals (40%)	0.44
Remanufactured Units	1.9	Brake Parts	1.0
Motor Parts	0.7	Front End Parts	0.9
Anti-Freeze/Coolant	1.5	Wipers and Blades	0.9
Gasket and Oil Seals (60%)	0.66	Equipment	0.9
Clutch Assemblies, Parts, etc.	1.0	Lamp Bulbs, Flashers and Sealed Beams	0.8
Engines (Small) and Parts	0.9	Bearings (Anti-Friction)	0.8
Grease and Oil (80%)	0.48	Tools (Small Hand)	0.8
Carburetors and Parts	0.6	Wire and Cable Products	0.7
Bearings (Motor)	0.6	Grease and Oil (20%)	0.6
Fuel Pumps and Parts	0.6	Wheels and Rims	0.3
Piston Rings	0.5	Tools (Power)	0.3
Thermostats	0.5	Automatic Transmission and Parts	0.3
Brass Fittings and Fuel Lines	0.3	All Other Lines (50%)	2.45
All Other Lines (50%)	2.45		
Total**	44.34	Total**	55.94

SOURCE: Derived from Table 3.4. Relative percentages were determined in consultation with industry representatives.

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*Starting-lighting-ignition (SLI) batteries are included with the internal-combustion-engine-related lines in conformance with the structure of the analysis. An initial gross impact reflecting losses due to the internal combustion engine will be contrasted with the net impact of the electric car with each of the four proposed electric vehicle batteries. The proposed lead-acid electric vehicle battery will also be manufactured to different specifications in terms of size, weight, and expected life and the cost per battery will be significantly higher.

**Does not add to 100% due to rounding.

TABLE 3.6

AUTO REPAIRS AND SERVICE

	Percent Cars Serviced/Year	Labor Time	Adjusted Percentage
Tune-Up*	66	2.1	33.4
Periodic Maintenance*	160	0.5	19.2
Brakes Relined	20	2.0	9.6
Exhaust System*	20	0.5	2.4
Wheels Balanced	16	0.8	3.1
Front Wheels Aligned	16	1.2	4.6
Headlight Beams Aimed	11	0.3	0.7
Cooling System*	11	0.35	0.9
Carburetor Overhauled or Replaced*	7	1.2	2.0
Generator Repaired	7	1.1	1.9
Voltage Regulator Adjusted or Replaced*	7	0.45	0.8
Body Repair	7	0.4	0.7
Fuel Pump Replaced*	6	0.35	0.5
Automatic Transmission Repaired	5	0.8	0.9
Major Engine Overhaul*	5	14.5	17.5
Fuel Pump Repaired*	4	0.35	0.3
Shock Absorbers Replaced	3	1.0	0.7
Standard Transmission Repaired*	2	0.7	0.3
Power Steering Repaired*	1	0.5	0.1
Standard Steering Repaired	1	0.9	0.2
Total	375		98.8**

SOURCE: Automotive Service Digest, Ref. 21, various Auto Repair Associations, and other industry sources.

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*Repairs directly related to internal combustion engine automobiles with the exception of Periodic Maintenance which is approximately 60% internal-combustion-engine-related and 40% non-engine-related.

**Does not add to 100% due to rounding.

recent federal legislation,* a number of sources were used to estimate the percentage of cars serviced per year. The following information was included: data on frequency of repair;[18] recommended replacement intervals for selected auto components;[19] frequency and price of three major engine related services performed routinely by garages;[20] and recommended periodic service and maintenance for average driving.[21] In the case of maintenance and service, the recommended intervals were adjusted to more accurately reflect the longer intervals reported in the frequency data.[18]

Frequency alone does not account for the actual percentage of a repair shop's business dependent on different categories of repairs. To address this problem, the percentage of cars serviced per year was weighted by the estimated labor time, in hours, required to perform the repair.[21] The adjusted percentage reflects the relative composition of an auto repair shop's business.

The average number of repairs or service items performed per car per year is 3.8. If more than one repair is performed in a given trip to the garage, the weighting factor may be overstated since the time necessary to perform a second repair decreases if the two repairs are related to the same system. Since we have no accurate way of assessing how often in fact this happens, we merely alert the reader to the consideration.

On the basis of the adjusted percentages in Table 3.6, we are able to assess internal combustion engine related repairs as 72 percent of the auto repair business and those repairs not dependent on the internal combustion engine as 28 percent.

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*Title II of the Motor Vehicle Information and Cost Savings Act of 1972 requires that the National Highway Traffic Safety Administration (NHTSA) develop ways of finding answers to questions regarding the cost of diagnosis and repair of mechanical or electrical malfunctions and body repair; and issue regulations on how this information shall be distributed to consumers by February 1975.

Comparing the auto supply sector with the auto repair sector, we observe that the percentage of sales related to the internal combustion engine is 44 percent; repairs, 72 percent. This difference is partially explained by the fact that 41 percent of auto supply sales are tires and batteries. Since installation of these items is included in the sales sector, they are not reflected in Table 3.6 as repairs. A recalculation of relative percentages of total sales of automotive lines excluding tires and batteries shows that 62 percent of sales are related to the internal combustion engine and 38 percent are non-related.

3.2.1 Impact on the Automotive Aftermarket

The specific impact of maximum utilization of electric cars on the automotive aftermarket will be reflected mainly in the 44 percent of total sales related to internal combustion engines and detailed in Table 3.4. The gross impact on employment and number of firms in the industry evaluated in terms of the total replacement of the internal combustion engine is estimated at a loss of 10,608 jobs in 1980; an additional 678 or a total of 11,286 jobs in 1990; and 3,662 additional jobs in 2000, or a total loss of 14,948.* The number of firms can be expected to decrease by approximately 44 percent. We would expect the smaller ones to be the most vulnerable because of their comparative lack of flexibility and diversity.

3.2.2 Impact on the Auto Repair Industry

The impact on the auto repair industry will be even greater since 72 percent of repair activity is related to the internal combustion engine. Total employment in the industry would be expected to decrease from 10,584 to 2,964 in 1980, a decrease of 7,620 jobs. In 1990 an additional 1,590 jobs would disappear for a total loss of 9,210. An additional 1,734 jobs would be lost in 2000 for a total decrease of 10,944 jobs at maximum utilization. The total number of firms could be expected to decrease by 72 percent and those remaining would be faced by significant inventory changes.

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*Calculated on the basis of projections from Task Report 4.

3.2.3 Impacts on Employment Due to Proposed Batteries

The net impact on employment of the use of electric cars is assessed by estimating the increases in employment in the automotive aftermarket and auto repair industry due to each of the four proposed batteries. By subtracting this increase from the employment loss determined through the replacement of the internal combustion engine, we are able to arrive at an estimated net loss for each of the four battery operated cars. The assumption implicit in the analysis is that employment per sale of battery will remain constant. There is the possibility of some differentiation in brand for any given battery design. It is also reasonable to assume that the markup on the given electric-vehicle batteries will be a lesser percentage of the total cost than the markup on SLI batteries. Since the electric-vehicle batteries are much more expensive, the potential profit to the dealer is higher even with a lesser percentage markup. These excess profits will encourage entry into the market by new firms. Selling costs will be driven up by the increased advertising expenses and additional required manpower in sales. In the worst case, employment in battery sales, which is now 8.6 percent of total auto supply sales, would increase on the average of say 50 percent per battery for an additional impact on battery sales employment of 4.3 percent, bringing the total to 12.9 percent of auto supply sales. Thus the impact on area employment would be an increase of 0.08 percent, which is considered minimal.

In assessing the impact of the lead-acid electric-vehicle battery, we consider both the "best case" and the "worst case." The best case has a life expectancy of 3.4 years compared to the current SLI battery life of 3 years. Since the best-case electric-vehicle lead-acid battery needs to be replaced approximately 12 percent less frequently than the current SLI battery, the decrease in total number of sales is expected to be approximately 12 percent. The worst case has a life expectancy of 1.3 years and total number of sales may be forecast to increase 2.3 times when compared with the present internal combustion engine battery.

SLI battery sales are responsible for 8.6 percent of total aftermarket sales, or an estimated 2074 jobs in 1980. The decrease in total employment in Auto Supply Stores and Wholesale Parts Distribution (SIC 5531 and 5013) due to reduced SLI battery sales may be expected to be about 12 percent of those jobs originally forecast, or 249 jobs in 1980; an additional 49 jobs may be lost in 1990 for a total decrease of 299 from the forecast 2495; an additional 51 jobs are forecast to be lost in the year 2000, bringing the total loss of employment in battery sales to 350 out of the 2,922 projected. These estimates reflect 100 percent utilization of electric cars. The number of jobs lost is expected to decrease linearly at lesser percentages of utilization.

The "worst case" lead-acid electric-vehicle battery can be expected to add 2,697 jobs or increase total employment in battery sales to a total of 4,770 jobs in 1980 since the number of battery sales will increase by a factor of 2.3. An additional increase of 968 jobs may be expected in 1990 for a total of 5,738 and 982 more jobs are forecast for 2000, increasing the 2,922 forecast to 6,720 at 100 percent utilization of electric cars. Again, we point out the expected linear relationship between the percentage of electric car use and the increase in the number of jobs.

Since the new lead-acid electric-vehicle battery pack will be approximately 60 times heavier and occupy more space than the SLI battery, the number of batteries kept in stock will be determined by the space available in a given facility. Given the alternatives of additional investment in physical plant and increased rate of turnover, the latter seems more likely to occur.

3.2.4 Impacts on Employment Due to Required Maintenance

The maintenance or replacement of the lead-acid electric-vehicle battery is responsible for a significant portion of auto-related employment. This impact, however, has been analyzed in Sec. 3.1 under the assumption that service stations will be more likely to perform these labor-intensive but simple functions since wage rates of service station attendants are considerably lower than those of auto mechanics.

The maintenance of motor and controls may well be performed by auto repair shops. Maintenance requirements are estimated at approximately one hour per year per car, and include checking the controls, motor, and infrequently adjusting or replacing the brushes. Total labor required to perform these tasks is estimated to be 2940 man years in 1980, 3,366 in 1990, and 3,800 in 2000. The same linear relationship is expected to hold for lesser percentages of electric car usage. The estimated changes in employment resulting from use of the lead-acid battery are summarized in Table 3.7.

The nickel-zinc battery is expected to require replacement about every 5.7 years. This interval exceeds the present SLI battery by 2.7 years and points to a decrease in total number of battery sales of 47 percent due to reduced frequency of replacement. The estimated impacts on employment are summarized in Table 3.8.

The zinc-chlorine battery is expected to have a replacement interval of 7.2 years, exceeding the present SLI battery by 4.2 years, and indicating a decrease in total number of battery sales of 58 percent. The estimated impact on employment is summarized in Table 3.8.

The lithium-sulfur battery has an expected life of 3 to 5 years. With a 3-year life expectancy, the total number of sales would remain unchanged and total employment in battery sales would be unaffected. The only increase in employment would result from motor and controller maintenance.* Given a 5-year life, the number of battery sales would decrease by 40 percent. The estimated impact on employment is summarized in Table 3.8.

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*An increase of 2,940 in 1980, 3,366 in 1990, and 3,800 in 2000.

TABLE 3.7

INCREASES IN EMPLOYMENT IN AUTOMOTIVE AFTERMARKET AND REPAIR INDUSTRY DUE EXCLUSIVELY TO USE OF LEAD-ACID BATTERY[*]

Employment	1980	1990	2000
Best Lead-Acid Battery			
Battery Sales:			
Forecast	2,073	2,495	2,922
Change	-249	-299	-350
Maintenance[**]	+2,940	+3,366	+3,800
Total	+4,764	+5,562	+6,372
Worst Lead-Acid Battery			
Battery Sales:			
Forecast	2,073	2,495	2,922
Change	+2,697	+3,243	+4,799
Maintenance[**]	+2,940	+3,366	+3,800
Total	+7,710	+9,104	+10,521

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[*] Reflects total change for each year independently, based on projections in Tables 4.5, 4.6, and 4.7 of Task Report 4.

[**] Motor and Controller only.

TABLE 3.8

INCREASES IN EMPLOYMENT IN AUTOMOTIVE AFTERMARKET AND REPAIR INDUSTRY

EXCLUSIVE USE OF THE NICKEL-ZINC BATTERY

Employment	1990	2000
Battery Sales:		
Forecast	2,495	2,922
Change	-1,172	-1,373
Maintenance[**]	+3,366	+3,800
Total	+4,689	+5,349

EXCLUSIVE USE OF THE ZINC-CHLORINE BATTERY

Employment	1990	2000
Battery Sales:		
Forecast	2,495	2,922
Change	-1,447	-1,695
Maintenance[**]	+3,366	+3,800
Total	+4,414	+5,027

EXCLUSIVE USE OF THE LITHIUM-SULFUR BATTERY

Employment	1990	2000
Battery Sales:		
Forecast	--	2,922
Change	--	-1,169
Maintenance[**]	--	+3,800
Total	--	+5,553

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[*] Reflects total change for each year independently.

[**] Motor and controller only.

The total net impact on employment in the automotive aftermarket and auto repair industry is summarized in Table 3.9. Since again the relationships are assumed linear, given mixes of batteries across years may be interpolated from the table.

From the point of view of national implementation, we would expect the same relative impacts. Intensity of impact on the aftermarket and auto repair industry would be expected to vary with concentration of cars, variations in levels of use, and environmental conditions affecting the life of the car.

3.3 MINOR IMPACTS

The analysis pursued in this subsection examines the impacts of electric car utilization on sectors we believe represent negligible effects, such as auto sales and wholesale distribution; tires and tire retreading; and automobile, motor, and control manufacturing. While some adjustments will be necessary in the short run, the impacts are expected to be minimal in the long run.

Although the impact of electric cars on auto sales will be direct, it is reasonable to assume that new car dealers will be able to shift their activities with a minimum of cost and effort. Dealer's inventories are mainly in cars and physical plant. Since their facility requirements will remain essentially unchanged with the introduction of electric cars, no additional capital investment directly related to plant capacity for the vehicles is foreseen. The constant turnover of cars should enable the dealer to gradually increase the proportion of electric cars as required. Dealer employees will need to familiarize themselves with specifications, performance characteristics, and other relevant information desired by consumers.

Total sales by new car dealers will be affected by the comparative cost of electric cars to the consumer, vehicle performance in terms of

TABLE 3.9

TOTAL NET IMPACT OF ELECTRIC CARS ON EMPLOYMENT AND PAYROLL IN THE AUTOMOTIVE AFTERMARKET AND AUTO REPAIR INDUSTRY

1980

	Total Employment*	Number of Jobs Lost	Percent of Originally Forecast Employment*	Payroll Decrease* (1972 $ Millions)
Lead-Acid Battery				
"Best Case"	21,229	13,464	39%	109.4
"Worst Case"	24,176	10,517	30%	84.1
		1990		
Lead-Acid Battery				
"Best CAse"	23,509	14,935	39%	139.7
"Worst Case"	27,048	11,396	30%	107.5
Nickel-Zinc Battery	22,636	15,808	41%	146.9
Zinc-Chlorine Battery	22,361	16,083	42%	150.4
		2000		
Lead-Acid Battery				
"Best Case"	29,652	19,520	40%	183.3
"Worst Case"	33,801	15,371	31%	142.1
Nickel-Zinc Battery	28,629	20,543	42%	192.5
Zinc-Chlorine Battery	28,307	20,865	42%	192.5
Lithium-Sulfur Battery				
"Best Case"	28,833	20,339	41%	187.9
"Worst Case"	30,002	19,170	39%	178.7

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*Includes SIC 5013, 5531, 7538 and 7539.

speed, range, frequency and cost of maintenance relative to the conventional car, changes in personal tastes and preferences and incentives for electric car use (or disincentives for conventional car use) created by public policy decisions.[*]

The average price of the conventional internal combustion engine automobile in 1973 dollars, weighted by the projected auto population share by class,[**] is estimated to be $3,618 in 1989, $3,282 in 1990, and $3,238 in the year 2000.[†] The electric car, including the initial battery, is estimated at $4,177 with the lead-acid battery, $5,885 with the nickel-zinc battery, $3,291 with the zinc-chlorine battery and $3,395 with the lithium-sulfur battery. A comparison of these costs by year is detailed in Table 3.10.

TABLE 3.10

COMPARISON OF PRICES FOR ELECTRIC CARS[*]
WITH INTERNAL COMBUSTION ENGINE CARS BY YEAR

	1980	1990	2000
Lead-Acid Battery Car	13% higher	21% higher	
Nickel-Zinc Battery Car		44% higher	45% higher
Zinc-Chlorine Battery Car		No change	2% higher
Lithium-Sulfur Battery Car			5% higher

[*] Including battery.

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[*] Examples of such incentives or disincentives are found in Ref. 23.

[**] Task Report 3, Fig. 6.6.

[†] Calculated in 1973 dollars and including costs of required emission control apparatus.

At a constant level of sales, the dollar value of dealer inventories will vary with the higher or lower price of the electric car relative to the conventional. For example, if in 1990 the nickel-zinc battery powered auto is 55 percent higher than the cost of the conventional car, the dealer's inventory would also be 55 percent higher. On the other hand, the higher cost of the electric vehicle may serve as an incentive for consumers to purchase new vehicles at less frequent intervals than the present national average of one out of eight households per year.[24]

The national average of total annual sales per dealer shows an upward trend over the last decade.[14] Since the average sales per dealer in the State of California are among the highest in the nation, we assume that the state will follow the national trend at a higher level. While total sales may vary somewhat from this upward trend, it is not apparent that this will significantly affect the total employment or number of firms in automobile sales and distribution (SIC 5012, 5511 and 5521) in the SCAB.

Dealerships will be affected by electric car utilization in the areas of service and repair. Approximately 15 percent of a dealership's total sales are attributable to service and repair activity.[14] Table 3.11 details recommended inventories for service departments of dealerships. Accepting this breakdown as a proxy for that portion of the dealer's repair activities which are internal-combustion-engine related, we observe that 50 percent of parts inventory is related and 44 percent is unrelated to internal combustion engines. Considerably less of the dealer's service and repair operation is related to internal combustion engines (cf. 72 percent for auto repair shops). This may be partially explained by the fact that the dealer operated shop performs a higher percentage of body repair work than does the general auto repair shop. Dealers also tend to emphasize service to newer cars which are under warranty, therefore they engage in less major engine work than auto repair shops.

TABLE 3.11

RECOMMENDED INVENTORIES FOR CAR DEALERS SERVICE AND REPAIR

	Percent of Total Inventory
Engine Cooling*	21%
Electrical	
Related to Internal Combustion Engine*	10
Unrelated to Internal Combustion Engine	2
Rear End and Transmission Accessories	12
Accessories	
Related to Internal Combustion Engine*	2
Unrelated to Internal Combustion Engine	2
Miscellaneous Mechanics**	
Related to Internal Combustion Engine*	23
Unrelated to Internal Combustion Engine	11
Body and Sheet Metal	17
Total	100%

SOURCE: Phone conversation with Mr. Ferron of the National Automobile Dealers Association (NADA), Washington, D.C. Related and unrelated relative percentages were estimated by those knowledgeable in the auto repair field.

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*Repair directly related to internal combustion engines.

**Includes:

Mechanical, fuel, brakes, exhaust, shocks, steering, and front end.

Since 15 percent of the dealership's total sales are in the service and repair category and 56 percent of that is related to internal combustion engines, we would expect a decrease of 8.4 percent in sales and employment in SIC 5511 and 5521. This impact can be evaluated as an average of 3,450 jobs lost at maximum utilization of electric cars. This figure is relatively constant over the three decades since little growth is projected in this area of employment through 2000. Decrease in total payroll is estimated to be 33.1 million in 1980; 35.6 million in 1990; and 38.2 million in 2000.

Impact on tire sales and retreading (SIC 5014 and 7534) will be slight in terms of employment and number of firms in these two classifications.* Present day tires should prove adequate, with minor modifications in production methods and specifications at most. Electric cars will require larger, more expensive tires due to the increased weight imposed by heavier batteries. Electric cars will accelerate less rapidly, thereby reducing wear on tires. At the same time, however, they will be heavier than conventional cars due to battery requirements. The increased weight counteracts the reduced wear from slower acceleration leaving tire mileage, number of tire sales, and tire retreading unaffected.

The regional impacts on auto manufacturing do not appear to be great. An informal survey of auto manufacturing firms (SIC 3717**) with an excess of 250 employees showed that activity is limited mainly to assembly operations and manufacturing of automobile accessories not related to new or replacement parts for equipment related to internal combustion engines.

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*Analysis of increase in cost of tires is found in Sec. 2.

**SIC 3717 formerly included Motor Vehicle and Parts Manufacturing and Assembly. The classification was changed as follows in 1972:

SIC 3711 Motor Vehicle Manufacturing
SIC 3712 Passenger Car Bodies
SIC 3714 Motor Vehicle Parts and Accessories

Source: County Business Patterns, 1972.

The firms approached in the survey account for approximately 40 percent of total employment in auto manufacturing in the Los Angeles area. Also established through the survey was the fact that the major engine-related parts are manufactured outside of the South Coast Air Basin. The parts are shipped to Los Angeles and autos are assembled in the area by the major manufacturers. An estimated 80 percent of those cars assembled in the area remain there. Little impact would be expected on assembly operations and passenger car body manufacturing since few changes would be required to convert present internal-combustion-engine designs for use with electric motors. The effect of large scale utilization of electric cars on the number of existing firms and employment in the auto manufacturing classification will be that normally expected as a result of design changes and new tooling requirements frequently encountered in present year-to-year model changes.

Table 3.12 contrasts percentage changes in factory sales with changes in employment in automobile manufacturing at the national level. Observing the average change and standard deviation of the two, we notice that employment has not been extremely sensitive to fluctuations in factory activity. We might therefore expect a lesser impact on employment as a result of short term fluctuations inherent in the changing market conditions foreseen with the implementation of electric cars, than we would expect if a closer relationship had been shown to exist between factory sales and employment in the past.

The impacts of electric car substitution on motor and controls manufacturing is minor in terms of national employment. The increase in activity is expected to be absorbed in regions already supporting these industry sectors because these two industries are characterized by sizeable levels of capital investment and less important transportation costs.

The projections for the dollar sales in millions of 1973 dollars for motor and control manufacturing for the years 1980, 1990 and 2000 are

TABLE 3.12

US AUTOMOBILE MANUFACTURING

	Employment*	Percent of Change	Factory Sales[24] (1972 $1,000)	Percent of Change
1967	765,314		7,436,764	
1968	774,246	1.17%	8,822,158	18.63%
1969	806,461	4.16	8,223,715	-6.78
1970	714,226	-11.44	6,546,817	-20.39
1971	746,929	4.58	8,584,592	31.13
1972	766,926	2.68	8,823,928	2.79
Average Change		0.23		5.08
Standard Deviation		6.66		20.35

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*County Business Patterns.

detailed in Table 3.13 along with the projected values of additional requirements given maximum substitution of electric cars. The percentage increases, also shown in Table 3.13, are used to derive the national employment impacts.

The projected requirements are derived by applying the expected auto sales figures for each of the decade intervals to the manufacturing cost of the required electrical equipment. These figures of $100 for the controls and $225 for the motor are taken from Ref. 12. These prices are presented in 1973 dollars for manufacturing costs in order to be consistent with the value of manufactured equipment from the Department of Commerce Report.[25]

These increases do not appear significant in terms of the national labor force. In fact, the total projected impacts are considerably smaller

TABLE 3.13

NATIONAL IMPACTS ON MOTOR (SIC 3621) AND INDUSTRIAL CONTROLS (SIC 3622) MANUFACTURING WITH 100 PERCENT ELECTRIC CAR USAGE IN LOS ANGELES

	1980	1990	2000
Forecasted Equipment Manufacturing Other Than Electric Vehicle			
Motors ($ Millions)[25]	3,800	6,073	9,705
Employment	100,000	159,813	255,402
Controls ($ Millions)[25]	2,000	3,650	6,661
Employment	50,000	91,246	166,517
Projected Additional Electric Vehicle Requirements			
Motor ($ Millions)	127	144	160
Controls ($ Millions)	56	64	71
Percentage Impact			
Motors	3.3%	2.4%	1.6%
Controls	2.8%	1.7%	1.1%
Employment Impact			
Motors	3,300	3,835	4,086
Controls	2,800	1,551	1,831

then the Commerce Department's projected yearly growth rates. In the past, 3 percent of this national activity has been in Los Angeles. If that trend continues, the impacts will be practically nil.

4 SECONDARY IMPACTS

The impacts upon transportation supplies and services are cumulative in their impact upon the South Coast Air Basin. Table 4.1 presents the change in economic activity which is expected to accrue to the region. This was derived, for each battery alternative, by summing the net change in activity expected for battery manufacturing, petroleum distribution, auto parts sales, auto repair, and auto sales. This impact is also shown as a percentage of projected baseline activity for employment and total personal income. Personal income is used, rather than payroll, as it is a better indicator of total regional economic activity.*

As was the case in Sec. 3, the impacts are assumed linear. That is, for any level of electric car substitution less than 100 percent, the impacts are proportional to the level of substitution. The activity change as a percent of baseline activity is shown to be fairly constant for each of the decade intervals.

This table should not be construed to predict any addition to the unemployment rolls which would result from a conversion to electric cars. This is a summation of the total dislocation in employment which would occur over the conversion period. It is reasonable to assume that this conversion would take place over a period of years and that much of this dislocation would accrue through normal attrition.

The reader will note that the worst lead-acid battery case shows a loss of employment and a gain in payroll. This is due to the change in the mix of employment. There is a loss of employment in the petroleum distribution sector including very low salaried service station attendants, and a corresponding gain in high salaried manufacturing employment. Table 4.2 shows this in more detail. The table contains data from projected 1990 activity. The structure of employment impacts varies little with the assumed decade of conversion. The structure does vary both by battery type and by employment category. As shown in Table 4.2, there is a

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*Salary income is about 70 percent of total personal income.

TABLE 4.1

IMPACT OF 100 PERCENT ELECTRIC CAR USAGE ON EMPLOYMENT AND INCOME IN THE LOS ANGELES AREA

	1980 Change in Activity		Change as Percent of SCAB Baseline	
	Employment	Payroll*	Employment	Personal Income
Best Lead-Acid Battery	-34,415	-164,111	-0.79%	-0.23%
Worst Lead-Acid Battery	- 9,642	96,539	-0.22	0.14
SCAB Employment Baseline[1]	4,335,000			
SCAB Personal Income[1]	69,830,000*			

	1990 Change in Activity		Change as Percent of SCAB Baseline	
	Employment	Payroll*	Employment	Personal Income
Best Lead-Acid Battery	-36,067	-186,986	-0.74%	-0.20%
Worst Lead-Acid Battery	- 7,574	140,870	-0.17	0.15
Nickel-Zinc Battery	-40,131	-168,602	-0.88	-0.18
Zinc-Chlorine Battery	-54,472	-338,756	-1.20	-0.36
SCAB Employment Baseline[1]	4,579,000			
SCAB Personal Income[1]	95,465,000*			

	2000 Change in Activity		Change as Percent of SCAB Baseline	
	Employment	Payroll*	Employment	Personal Income
Nickel-Zinc Battery	-45,594	-299,353	-0.91%	-0.22
Zinc-Chlorine Battery	-61,420	-407,837	-1.21	-0.30
Best Lithium-Sulfur Battery	-63,143	-425,225	-1.25	-0.31
Worst Lithium-Sulfur Battery	-58,050	-368,937	-1.15	-0.27
SCAB Employment Baseline[1]	5,025,000			
SCAB Personal Income[1]	135,293,000*			

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*1972 dollars in thousands.

TABLE 4.2

STRUCTURE OF EMPLOYMENT CHANGES

	Auto Service	Auto Sales	Manufacturing	Petroleum Distribution
Average Salary*	9.3	10.3	11.8	5.7
Employment Impacts				
Best Lead-Acid	-14,953	-3,450	14,774	-32,456
Worst Lead-Acid	-11,396	-3,450	39,728	-32,456
Nickel-Zinc	-15,808	-3,450	20,637	-41,510
Zinc-Chloride	-16,083	-3,450	6,571	-41,510
Best Lithium-Sulfur	-15,634	-3,450	4,579	-41,510
Worst Lithium-Sulfur	-14,636	-3,450	8,054	-41,510
Average	-14,751	-3,450	15,724	-38,492
Standard Deviation	1,730	0	13,176	4,675

*1972 $thousands.

considerable gain in higher skilled and higher paid manufacturing employees with the lead-acid and nickel-zinc battery types. In all cases, there is a considerable loss of employment in the lower paid and lower skilled service station employees, a group that could have difficulty finding alternative employment.

In addition to impacts upon consumers and some employment sectors, the conversion to electric cars has the potential to disturb the economic equilibrium in the region. This impact is difficult to quantify in a region as large and complex as Los Angeles. Some general assessments are possible, however. Recall that consumers expenditures for private transportation vary with electric car types and that there is a consistently negative input upon regional employment opportunities with electric car substitution. If the consumer is paying more and there are fewer jobs being generated, these funds are being diverted. In this case, the funds are diverted outside the region to procure the extra materials (lead, nickel, zinc, etc.) required for battery production. These materials are not available within the region.

Table 4.3 shows the potential impacts upon the Los Angeles economy for various electric car scenarios. These impacts were estimated by calculating the wholesale cost of goods which would be procured outside the region. The benefits of retail activity accrue to the region irrespective of the origin of the product. These wholesale costs were adjusted to reflect the traditional multiplier effect in order to estimate the total potential impact.

There are competitive market factors which make it unlikely that Los Angeles would experience the full extent of those potential impacts. To experience the full impact, regional activity would have to decrease

TABLE 4.3

POTENTIAL CUMULATIVE IMPACTS IN LOS ANGELES

		Change in Regional Payroll	
		$ Millions	Percent of Total
1980	Lead-Acid Battery: Best Case	241.4	0.5%
	Lead-Acid Battery: Worst Case	-3,085.7	-7.1
1990	Lead-Acid Battery: Best Case	6.7	0.01
	Lead-Acid Battery: Worst Case	-3,797.3	-8.2
	Nickel-Zinc Battery	-2,208.4	-4.8
	Zinc-Chlorine Battery	2,558.5	5.6
2000	Nickel-Zinc Battery	-2,568.8	-5.1
	Zinc-Chlorine Battery	2,812.0	5.6
	Lithium-Sulfur Battery: Best Case	2,530.8	5.1
	Lithium-Sulfur Battery: Worst Case	1,922.8	3.8

proportional to the increase in materials imports. It is likely that the region would substitute these materials for other imports (e.g., refrigerators), thus keeping their level of economic activity stable. Alternatively, if imports increased, that increasingly available portion of the labor pool would be available at some lower price. This would lower the cost of exports and lead toward a new equilibrium position for the region.

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TASK REPORT 10

USAGE OF ELECTRIC CARS IN THE LOS ANGELES REGION, 1980-2000

W.F. Hamilton

10-A

ABSTRACT

Future usage is estimated for four-passenger battery-electric cars with ranges between overnight recharges of 55 miles before 1980 and 145 miles thereafter. A new analysis of the Los Angeles 1967 travel survey provides basic data: distributions of daily driving mileages, and availability of off-street parking. On this basis, one million second cars at single-family households, or 17 percent of 1980 Los Angeles area cars, could be replaced by the 1980 electric car with very little loss of capability, while the advanced battery cars could replace 46 percent of the area's cars in 1990 and 74 percent by 2000.

From a review of these estimates, plus current market share data for conventional subcompacts and results of consumer surveys regarding electric cars, free-market electric car populations for the Los Angeles region are subjectively estimated at under 1 percent in 1980, about 5 percent in 1990, and about 10 percent by 2000. Much higher populations could be supported by potential production capability: near 75 percent by 1990. Hypothetical intermediate electric car populations ranging from 23 to 46 percent in 1990 are then selected for eventual use in analyzing potential impacts of electric cars on regional environment, energy, and economy. Until cost disadvantages of electric cars are eliminated by improved battery technology, powerful legislative incentives would be required to bring about these hypothetical usages.

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1 INTRODUCTION

The objective of this paper is to estimate likely levels of electric car use in 1980, 1990, and 2000 in the Los Angeles region. These estimated levels of use are eventually to be utilized in an overall evaluation of electric car impacts. The specific region of concern is California's South Coast Air Basin, which includes greater Los Angeles, and the usage characteristics required are the numbers and daily mileages of the electric cars.

Even after the characteristics of future electric cars have been detailed, estimating their use is difficult. There is little data or experience to go on, since electric cars have not found much application since the early years of this century. On the one hand, electric cars could do much of what conventional cars now actually do. On the other hand, however, the electric cars are likely to be less than competitive with the conventional alternative in dollar cost, in performance, in overall accommodations, and--more important--in daily range. The existing marketplace offers some clue to the acceptability of cars which are smaller, or more expensive, or less powerful than most of their competition, but it tells us nothing about cars with a stringent daily range limitation.

Were there nothing else involved, prospects for substantial use of electric cars would be dim indeed. But other factors are very much involved: the undesirable side-effects of the conventional automobile on the quality of urban life; the prospects that electric cars might contribute much less to pollution of the urban environment; and the potential independence of electric cars from dwindling petroleum reserves. These are presently externalities to the market transactions wherein consumers choose between electric and conventional automobiles, but they are likely to play an increasingly important role in the marketplace as public policy and collective action increasingly regulate the characteristics and the usage of private automobiles. Beyond whatever today's market shows, then, about the electric car's potential, there is a real prospect that public policy will greatly enhance its relative desirability.

The effect of public policy is particularly important in this study of electric car impact. Without the support of positive public policy, it is quite conceivable that the most likely level of electric car use would remain near zero, making impacts trivial. Simply to make this impact study useful, then, it is essential that sufficiently influential public policy be assumed to justify estimates of substantial usage. Such policy may not be the most likely future course; but the usage estimates developed here need not be confined to the most likely possibility.

In the next section, this paper sets forth briefly its overall approach to estimating reasonable levels of electric car use. In subsequent sections, it deals with each step in the approach: the current patterns of automobile use, the applicability of electric cars to them, the potential free-market penetration of electric cars, and possible limitations of production capability. Finally, it discusses alternative public policies for electric car use, required measures for their implementation, and elemental scenarios for introducing alternative electric cars in 1980, 1990, and 2000.

2 APPROACH TO USAGE ESTIMATION

Because data is relatively scarce for incisive estimation of electric car usage, a great many uncertainties arise in the estimation process and its results. It is thus appropriate to develop upper and lower bounds on usage which can be established relatively firmly, and then to develop within these bounds different estimates which might be associated with different public policies for urban transportation.

The most striking feature of the electric car, at least for the next decade, is its limited range between recharges, which may be on the order of 50 miles in urban use. Far more than sluggish performance, limited accommodation, or increased cost, this range limitation distinguishes the electric car from competing conventional automobiles.

The effect of this range limitation depends significantly on the overall institutional system within which electric cars are operated. At one extreme, all electric cars will be recharged only overnight, and consequently will be limited to a daily range no more than the range between recharges. At the other extreme, electric car batteries will be replaceable in minutes at service stations which will maintain a supply of recharged battery packs just as conventional service stations maintain large tanks of fuel for conventional cars. In this situation, motorists' daily range would be virtually unlimited; the only penalty of the limited range between recharges would be more frequent stops for "refueling."

Either of these extremes seems technically feasible. The latter, however, is institutionally complex, requiring not only proper designing of auto battery packs for easy replacement, but networks of service stations equipped with the necessary handling equipment and high-power recharge capability. A single battery pack may weigh 1,500 pounds, for example, while a hundred battery packs on recharge might easily require a thousand kilowatts of charging power. More complex still would be the development of an equitable system for leasing battery packs, each worth well over a thousand dollars, for each 50-mile use of electric automobiles, especially since the conditions of use substantially affect battery life.

Because of its simplicity, the home-recharge system of electric car use is the most reasonable prospect for the introduction of electric cars. Once electric cars thus became numerous, home recharge would surely be supplemented by recharge facilities at places of work, and at parking lots generally; and eventually battery replacement stations and systems might be expected to develop through successful competition with the home-recharge system.

The initial arrangement of home recharge might thus give way eventually to the more elaborate system of battery replacement--but only so long as the stringent range limitation remains. Were range between recharges significantly increased, the motivation for the battery replacement system would largely disappear.

The introduction of high-performance batteries with a range between recharges of 150 miles or more is projected in this study before 1990.[1] In consequence, battery replacement systems seem likely to be obviated before they have had a chance to grow to fruition.

Thus the usage estimates developed in this report are based on the home recharge system, that is, on daily range limited to the range between recharges of the electric cars. If anything, this will tend to make total usage estimates conservative. In any case, it makes the importance of daily range, and its compatibility with typical travel needs, crucial in the estimation procedure.

The approach to usage estimation undertaken in this paper proceeds as follows:

- Analyze usage patterns of conventional automobiles, emphasizing the frequency with which given daily ranges are exceeded, and the probable feasibility of home recharge.

- Determine prospective numbers of automobiles which are driven and parked in such manner that electric cars could accomplish essentially all their functions.
- Estimate an upper bound on electric car use based on replacement of appropriate conventional cars and possible limitations due to likely lead times in introducing electric cars into the automobile population.
- Estimate a lower bound on electric car use by considering potential free-market penetration likely, given the relative performance, accommodations, and cost of future electric cars relative to competitive conventional automobiles.
- Select intermediate levels of electric car use which might be sought by public policy, outline quantitatively the measures needed to realize these policy levels of use, and hypothesize elemental scenarios for introducing alternative electric cars to meet the usage levels in 1980, 1990, and 2000.

3 PATTERNS OF CONVENTIONAL CAR USE

Overall transportation projections for the Los Angeles area were developed elsewhere in this study.[2] Their overall result is reproduced here as Table 3.1, which shows average individual car usage projected to future years for the South Coast Air Basin.

Four passenger electric cars characterized for future years in this study are briefly described in Table 3.2.[3] Evidently, the daily range capability of even the lead-acid battery cars is substantially greater than average daily usage, which is about 30 miles. Costs and other aspects of electric cars will be discussed in relation to their probable use in Secs. 6-8.

Though average usage may be well within electric car range, almost every automobile is likely to be driven more than the electric car range on some percentage of days. Only if this percentage is small is the conventional automobile a reasonable candidate for replacement by the electric car. The probability that conventional cars are driven more than a given distance in a day thus becomes the critical factor in estimating the potential or applicability of electric cars in urban travel.

In the last two decades, tremendous quantities of urban travel data have been gathered, analyzed, and expanded into projections for the future. A typical result is reproduced as Fig. 3.1, which shows the distribution of trip times less than a given number of minutes. With the average speeds of Table 3.1, trip times may be approximately converted into trip distances, and thus the probability of a work trip longer than a given distance may be readily derived. Obviously, there are very few trips surveyed or forecasted in Los Angeles with lengths greater than 50 minutes or roughly 25 miles, and thus beyond the daily capability of even the 1980 electric car. As Table 3.1 shows, however, most cars are driven on four or five daily trips. Thus the distribution of individual trip distances is not by itself a good indicator of electric car applicability.

TABLE 3.1

BASELINE AUTO TRAVEL PROJECTIONS--SOUTH COAST BASIN

	1980	1990	2000
Daily Vehicle-Miles, millions	167	196	228
Percent on Freeways	39	42	45
Percent on Streets	61	58	55
Daily Miles Per Vehicle	29.3	29.2	30.0
Daily Trips Per Vehicle	4.6	4.6	4.6
Daily Minutes Per Vehicle	53	54.7	56.2
Miles Per Trip	6.15	6.35	6.52
Minutes Per Trip	11.5	11.9	12.2
Average Speed, mph	32.0	32.0	32.0

TABLE 3.2

ELECTRIC CAR CHARACTERIZATIONS

Battery Type	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Urban Driving Range* (Ref. 1)	54 mi	144 mi	145 mi	139 mi
Test Weight (Ref. 1), with 450-Pound Payload	3,975 lb	3,530 lb	2,950 lb	2,655 lb
Initial Cost** (Ref. 4)	$4,177	$7,325	$3,491	$3,395
Total Per-Mile Cost,** cents (Ref. 4)	16¢-21.6¢	21.2¢	11.7¢	12.2¢-13.1¢
Estimated Availability (Ref. 1)	1978	1980	1985	1990

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*On SAE Metropolitan Driving Cycle.

**In 1973 dollars, including battery cost. Initial costs and life-cycle per-mile costs (including finance charges) of a comparable ICE subcompact in 1973 were $2,270 and 13.3¢, respectively.

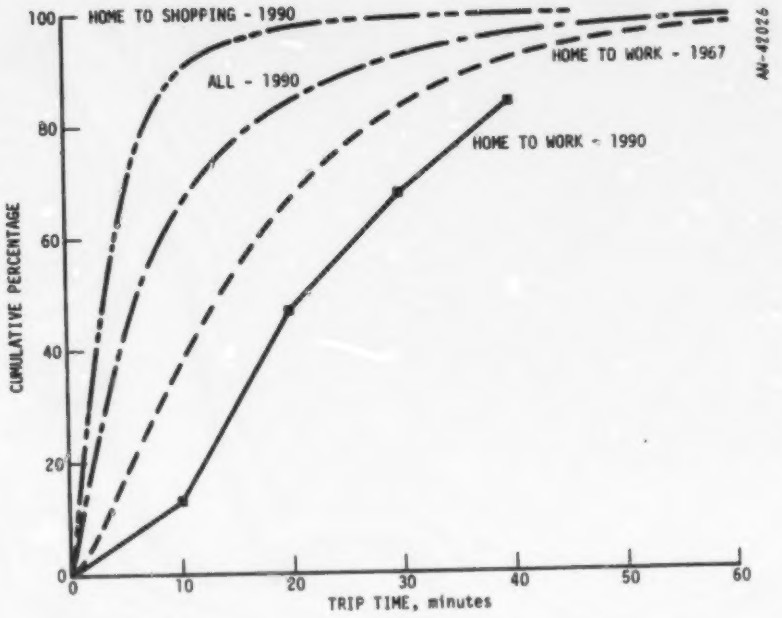

Figure 3.1. Distributions of Trip Times (From Ref. 5)

The real question is how often the total of all trip mileages in a day is likely to exceed the range of the electric car.

It happens that the wealth of urban travel analysis has been almost entirely focused on the individual vehicle or person trip as a unit of analysis, rather than daily vehicle or person travel. Distributions of daily vehicle mileage do not appear in the many urban travel analyses available in the literature to this study. Even the definitive experimental investigation of individual automobile usage in Los Angeles emphasizes distribution of trip distances and nowhere presents distributions of daily travel distances.[6]

The only source of daily travel distributions located in this study was developed specifically for estimating the potential market for electric vehicles.[7] Its results are plotted in Fig. 3.2, which shows the probability that cars in three different annual usage classes will

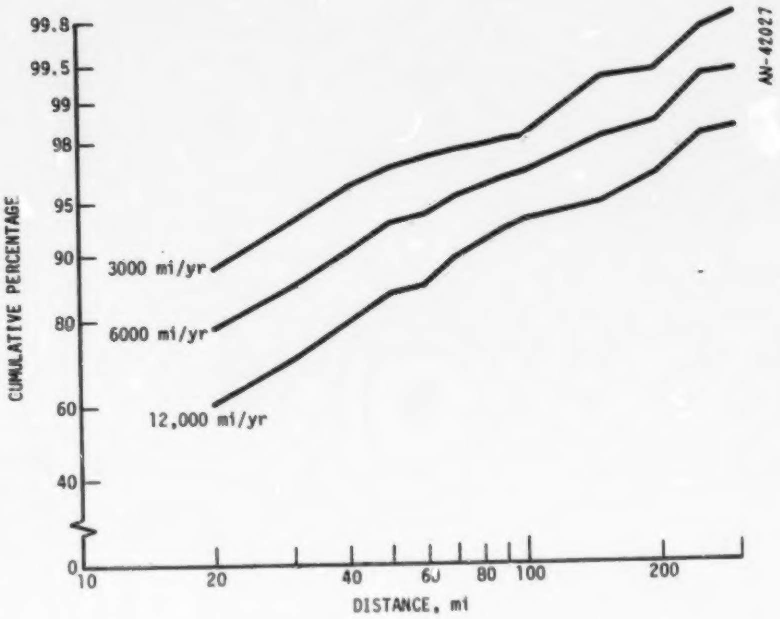

Figure 3.2. Distributions of Daily Mileages for Automobiles, by Annual Usage Class (From Ref. 7)

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will be driven less than a given mileage in a day. This analysis further estimates that some 15 percent of US cars are in the 3,000-mile-per-year-or under class, 40 percent are in the 6,000 mpy-or-under class, and 70 percent are in the 12,000 mpy-or-under class.

Though the information of Fig. 3.2 is a great step forward from trip-based analyses towards the requirements of this study, it is less than ideal in several respects. First, it is based primarily on average travel distances observed in Chicago in 1956. Thus it may not be appropriate for 1990 Los Angeles. Second, it relies entirely on assumed distribution forms for urban travel: Poisson distributions were assumed for the distributions of both daily trip numbers and trip distances, and only the average values of these distributions were obtained from observation. Third, the usage classes by miles per year are inappropriate where market penetration must be estimated, because they are correlated with car age. As Table 3.3 shows, cars which are driven very little are generally very old. While a new electric car may be immediately applicable

TABLE 3.3

ANNUAL MILEAGE VERSUS CAR AGE (from Refs. 8 and 9)

	Average Annual Mileage (light-duty vehicles)	
Age, years	US	California
1	15,900	15,000
2	15,000	13,000
3	14,000	11,000
4	13,100	9,600
5	12,200	8,400
6	11,300	7,000
7	10,300	5,300
8	9,400	5,000
9	8,500	4,400
10	7,600	4,200
>10	6,700	3,500

to the functions of a ten-year-old conventional car, it is probably not a reasonable competitor for replacing the old car because it necessarily carries a new-car price tag. In the longer run, electric cars could "trickle down" through the system and become competitors for inexpensive conventional used cars--but only if the electrics can gain a toe-hold somewhere else in the auto market.

Because information on daily car use was not available in the literature, it became necessary to reprocess extensive travel survey data to deduce distributions of daily car use, as opposed to distributions of individual trip characteristics as developed in past studies.

4 LOS ANGELES SURVEY DATA ANALYSIS

As noted in Ref. 1, the basic source of Los Angeles transportation data is the 1967 survey conducted by the Los Angeles Regional Transportation Study (LARTS). The survey consisted of intensive interviews at a 1% sample of households in the LARTS area during the fall of 1967.[5] Following up on previous notifications and requests for cooperation through the mails, the interviewers recorded data about each household, about its members, and about trips they had taken on the survey day. For each trip, the addresses of origin and destination, the mode of travel, the identity of the traveler, the purpose of the trip, and a host of other descriptions such as time and duration, freeway usage, parking, and vehicle occupancy were all recorded.

After coding and keypunching for computer processing, the data base from the interviews became the principal basis for developing analyses, models, and projections of Los Angeles travel demand. But because the individual trip, rather than the day's travel by an individual or vehicle, was the basic analytic unit in this processing, the results are not directly applicable to the question of electric car range adequacy.

To investigate typical vehicle use in an entire day, the Los Angeles survey data was reprocessed in this study. Several reels of tape provided by LARTS described each of almost 200,000 trips detailed in the interviews. A separate reel of tape contained descriptions of households whose members made these trips.

A computer program was written to read the trip and housing tapes. Basically, the program accumulated total mileages traveled during the survey day for occupants and vehicles of each individual household. From this basic result, it then compiled distributions of total travel mileage, so that the fraction of persons or vehicles traveling more than a given total mileage on the survey day could be determined.

Ideally, the program might have compiled distributions only for total vehicle travel on the survey day. Unfortunately, however, the interviews did not record which vehicle at a multi-vehicle household was used for each of the trips reported by members of that household. Thus the program was only able to develop vehicle mileage distributions for single-car households. The interviews did record which individual of the household made each trip, which made it possible to develop distributions of daily travel for individual drivers of the households.

The computer program employed an approximate airline distance rather than the actual over-the-road distance for each reported trip. Though the interviews obtained addresses of trip origins and destinations, this level of detail was lost as subsequent coding assigned each address to one of some 1200 traffic zones into which the study region was divided. Only the zones of origin and destination appeared on the tapes. Coordinates of zone centroids (centers of gravity of population) were provided by LARTS; but no detailed representation of the street and highway network could readily be obtained and utilized to determine actual driving distances. Consequently, simple straight-line distances between zone centroids were used initially as trip distances, and adjusted upward later.

For trips which began and ended in the same zone, the program employed an average intrazonal travel distance which had been precomputed for each zone. This distance was taken to be half the airline distance from the zone centroid to the centroid of the nearest neighboring zone.

In the processing of the survey data, attention was focused on those households reporting automobile trip details on the survey day. In consequence, almost a third of the survey households were not included in the development of daily mileage distributions.

Table 4.1 details the reasons for omissions of households and trips in developing the set of households and trips in the sample for which

TABLE 4.1

SAMPLE SELECTION FROM LOS ANGELES 1967 HOME-INTERVIEW STUDY

Total Survey Households		33,030
Total Survey Trips		195,693
Ommitted Households		10,704
unoccupied	21%	
no cars	27%	
unused cars	22%	
no trip data	30%	
Omitted Trips		190
erroneous ID	35	
erroneous zone name	155	
Sample Households		22,326
Associated Auto Driver Trips		130,800

distributions were calculated. Of almost 11,000 households omitted, the largest single category indicated auto driver trips on the household data tape but had no corresponding trip descriptions anywhere on the trip tape. LARTS personnel suggest that this is at least partly the result of unusable trip descriptions given by survey respondents. Somewhat smaller numbers of households were also omitted for each of three reasons: they were vacant, had no cars, or reported no use of their cars. Of the omitted households, 87 had descriptive data which were not in the standard format and were unreadable by the processing program.

Only 190 auto driver trips were omitted from the 130,000 reported by households in the processed sample. Most of these stated zone names of origin or destination which were not in the list of zone names actually employed in the analysis. A few others had identification numbers which did not correspond to any of the household identification numbers.

A flow chart and listing of the computer program which processed the sample of Table 4.1 appear in the appendix.

The overall characteristics of the processed sample are summarized in Table 4.2. Overnight and external trips--trips beginning or ending outside the study region--amounted to less than 1 percent of all trips. Neither were included in daily travel distributions, since in the case of external trips, no distance could be associated with them, and because data on such travel is available from the National Transportation Survey of 1967. Intrazonal trips, though they amounted to 18 percent of all trips, accounted for only 3 percent of total travel distance. Thus the precise distance of each intrazonal trip is probably unimportant in total daily mileages, and the probably inaccuracies in the estimates used for intrazonal trip lengths will not significantly degrade results.

TABLE 4.2

CHARACTERISTICS OF SAMPLE AUTO DRIVER TRIPS

Total trip distance	616,889 miles
Intrazonal trip distance	17,815 miles
Total trips	130,800
Intrazonal trips	23,503
Overnight trips	516
External trips	584

"Cars" were defined in the survey processing for this project as both passenger automobiles and pickup trucks. In Los Angeles, it appears that most pickup trucks are used in essentially the same manner as personal automobiles. The survey asked whether each reported vehicle was capable of "long-distance commuting"; all but 3 percent of vehicles were included in this category.

In Los Angeles there are essentially as many cars as drivers. On the survey day, 88 percent of all drivers reporting trips came from households with as many or more cars than drivers reporting trips. Thus in the great majority of cases, driver travel was not constrained by unavailability of a car.

This important point is the key to deriving useful results from a survey which did not report which vehicle was used for each trip. Essentially, it implies that driver travel and vehicle travel were similar, since 88 percent of drivers had vehicles available to them. There is no absolute assurance, of course, that drivers all used available vehicles, rather than waiting to take turns on a lesser number of preferred vehicles. Nevertheless, this seems likely to have been the case.

After computer processing of survey trips, a substantial adjustment was introduced to make results more realistic. Adjustment is necessary for two reasons: first, because airline distances rather than over-the-road distances, were developed in the program; and second, because comparisons with other data indicate that in the survey itself, respondents neglected to report a substantial amount of their actual travel.

Evidence of under-reporting is presented in Table 4.3 which shows the discrepancy between survey results and independent control data with which the results were compared. The first four characteristics noted in Table 4.3 are all modestly under-reported, in approximately the same amount, as might be expected in an origin-destination survey. The corridor checks and vehicle miles of travel, however, are very much lower than might be expected. Original screen line crossings--counts of vehicle movements across two lines bisecting the study area from north

TABLE 4.3

COMPARISON OF LOS ANGELES 1967 HOME-INTERVIEW SURVEY RESULTS WITH INDEPENDENT CONTROLS (from Ref. 5)

Characteristic	Discrepancy	Control
Population	-5.7%	Data from various government agencies
Housing Units	-4.0	Data from various government agencies
Auto Ownership	-8.2	Dept. of Motor Vehicles registration data
Resident Cordon Check[*]	-7.4	External survey
Screenline Crossings[**]		Actual ground count
Ventura/L.A. boundary	-6.4	
L.A./San Bdo./Riv. boundary	-6.8	
Corridor Checks		Actual ground count
(average of 7 corridors)	-20.2	
Vehicle Miles of Travel		
Total	-18.6	National Highway Functional Classification Study
Freeways Only	-16.8	1967 Annual Traffic Census

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[*] Drivers entering and leaving the study area were interviewed as they crossed a cordon line surrounding the area, to obtain information on travel by persons non-resident in the area. Data from resident drivers obtained at the cordon was compared with external trip data from the home interview survey.

[**] Discrepancies are after survey adjustment; see text for explanation.

to south--were apparently also very much lower; values in Table 4.3, according to LARTS personnel, apply to screen line counts _after adjustment_, even though no adjustment is mentioned in the text. All other discrepancies in Table 4.3 are before adjustments.

The LARTS adjustment of survey results was accomplished by increasing numbers of reported trips by up to 80 percent, according to trip type, with overall upward adjustment of trip numbers equal to about 30 percent. The trip types increased most were those judged most likely to be neglected and under-reported in a survey; work trips, which presumably are unlikely to be forgotten, were not increased at all.

In processing of the LARTS data tapes for this study, individual adjustment of trip types was not feasible. Accordingly, the total number of trips was simply increased by 30 percent. In consequence, mileage distributions for individuals and drivers were uniformly increased 30 percent.

To account for over-the-road routing rather than airline distances between zones, total mileages were additionally adjusted upwards by 23 percent. This figure was chosen to make the adjusted average trip length equal to that in LARTS network model runs.* Furthermore the 23-percent adjustment is in reasonable agreement with a simple analysis. If trips are made between points randomly selected in a rectangular street grid, the average over-the-road travel distance will be greater than the airline distance by a factor of $4/\pi$, a 27-percent adjustment. In the real world, however, it seems likely that trips will not be uniformly distributed in direction, and that in addition, there will be important diagonal streets and freeways reducing travel distances which otherwise would be required in a rectangular grid.

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*As reported in Ref. 2, the home-interview survey is the basis for continuing computer analyses and forecasting. The principal computer outputs are trip production runs, summarizing and projecting trip-making, and network model runs, showing trip routings and total traffic levels on roadways which might result.

The total adjustment applied in this study is thus +60 percent; +23 percent in individual trip distances due to actual rather than airline routings; and 30 percent in number of trips taken, due to apparent underreporting of trips in the survey. After adjustment, the processed sample of travel in Table 4.1 appears in reasonable agreement with other analyses and data, as indicated in Table 4.4. The miles per trip agree not only with the LARTS network model run, but very closely with the average travel distance used by Kalish[7] in the previous study of daily vehicle usage. The number of trips per car is moderately higher than that of the network model run, as might be expected since in the sample, cars which were not used on the survey day were dismissed from this average. About 7 percent of cars were in this category; if they were included, the trips per car after adjustment would be very close to that of the network model run. The lower value for trips per car reported by Kalish may be explained

TABLE 4.4

ADJUSTED SAMPLE AVERAGES

Travel Characteristic	Adjusted Sample	Comparable Value	Source of Comparison
Miles per trip	5.8	5.8	Network Model Run
		5.7	Kalish[7]
Trips per car	4.9	4.6	Network Model Run
		3.7	Kalish[7]
Miles per car	28.6	27.6	Trip Production and Network Model Runs
		24.9	DOT Highway Statistics - 1969
		21.0	Kalish[7]

by its derivation from data in another city (Chicago) some years ago (1967). Overall, the average daily car mileage is reasonably close to that implied by the LARTS models and DOT statistics. The adjusted sample differs from the DOT figure because cars which were not used on the survey day are not included, and because long-distance travel is not included in the sample. These omissions tend to compensate one another, but not completely. According to the National Travel Survey of 1967, there were 3.6 annual long-distance or overnight trips per vehicle, on the average, of about 240 miles each, amounting to 2.4 miles per day which is not included in the adjusted sample mileage. The omission of unused cars from the average, on the other hand, means the adjusted sample is a little over 2 miles per day higher than it would otherwise be.

The effects of the adjustments of the survey distributions are shown in Fig. 4.1. The upper curve in this figure shows the cumulative total number of drivers in the survey who drove less than the indicated mileage on the survey day, before any adjustment. The lower curve shows the results of the 23-percent adjustment for road rather than airline mileage, and the 60 percent total adjustment to compensate for under-reporting in addition. Also shown in Fig. 4.1 are the daily mileage capabilities for the particular electric cars of this study. The adjustment is considerable: based on the raw data, the four-passenger lead-acid battery car would be adequate for 93 percent of the daily mileage; but based on the adjusted data, it would be adequate for only 83 percent.

For comparison, the result of Ref. 7 is included in Fig. 4.1, for cars driven 12,000 miles per year. Since that study included overnight and long-distance travel, it is to be expected that it would deviate increasingly with distance from the other curves of the figure. Near the lower electric car ranges, however, and in the vicinity of most daily travel distances, it is in reasonable agreement with the adjusted distributions of Los Angeles mileages. This may be surprising in view of the basis of this previous study, which assumed simple mathematical

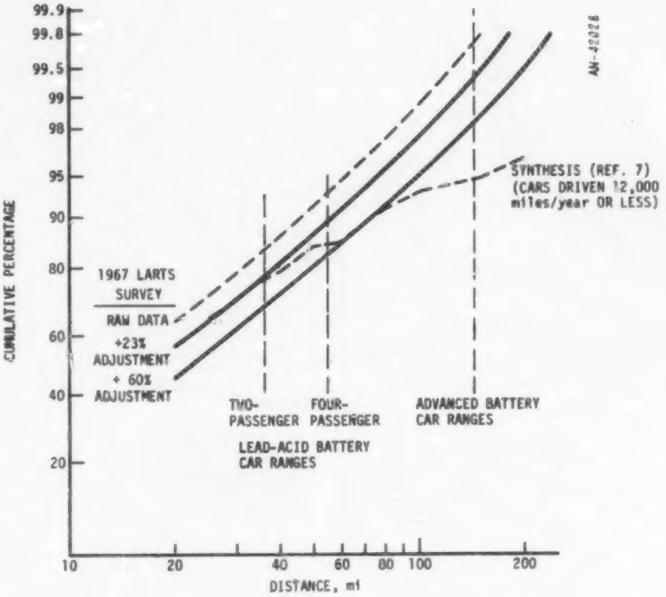

Figure 4.1. Adjustments of Surveyed Daily Mileage Distributions

forms for the distributions involved in its synthesis, and for distribution parameters relied on 1956 Chicago data.

The basic adjusted distributions of daily travel distances from the Los Angeles survey are shown in Fig. 4.2. This figure shows the most important of several categories of travel for which distributions were produced. The first of these is for the daily travel distance of drivers who had cars available to them without interference on the survey day--drivers, that is, from households reporting at least as many cars as drivers on the survey day. The other distribution shown is for the daily travel of a single car in households reporting one car driven by two drivers on the survey day. In such instances, it is to be expected that the travel desires of two drivers would cause the car to be used more than a single driver might use it, but less than two separate cars. This is the case: cars used by two drivers typically travel 50 to 80 percent further in a day than cars used exclusively by single drivers.

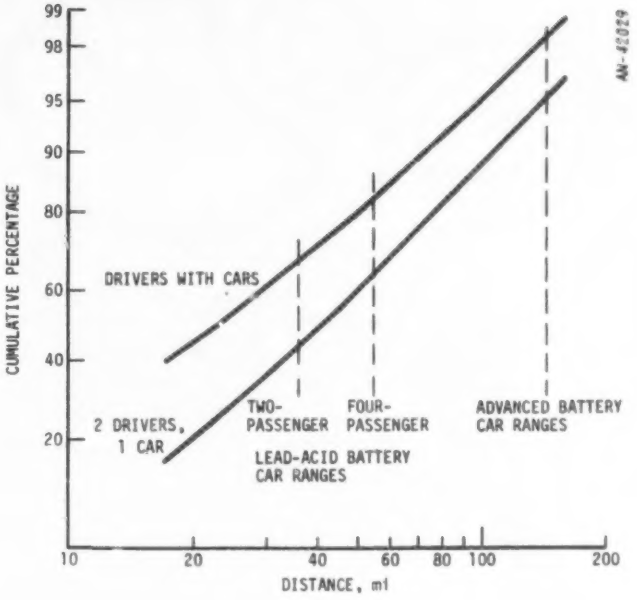

Figure 4.2. Adjusted Distributions of Daily Travel, Los Angeles Region, 1967

Distributions were also developed for other cases, such as individual drivers in 1-, 2-, and 3-car households. They are not much different, however, from that for drivers with cars in Fig. 4.2.

If several drivers using a single car were common in Los Angeles, the daily range requirement for electric cars would be substantially increased and consequently much more difficult and expensive to meet. Such, however, is not the case. Processing of the 1967 Los Angeles survey shows that very few drivers did not have cars available on the survey day. And with increasing automobile ownership rates, unavailability of cars to drivers will be even less frequent in the future. Table 4.5 shows that on the survey day 88 percent of drivers had cars available to them. Thus it seems reasonable to employ distributions of daily travel for these drivers as representative of what electric cars will be required to do in the future, when individual cars for drivers will be even more generally available.

TABLE 4.5

SURVEY AVAILABILITY OF CARS TO DRIVERS

Los Angeles Area

Percent of area drivers with cars available to them

in 1-car households	26%
in 2-car households	46%
in 3-car households	13%
in 4-car households	4%
in all households	88%

Percent of area drivers without cars available to them

in 1-car households	7%
in multi-car households	5%
in all households	12%

In conclusion, it should be noted that a basic assumption is required to make survey results useful. This assumption is that the distribution of daily mileages for all days in the life of a single typical car is the same as the distribution of daily mileages for the survey sample of cars on a single day. It will be implicit in the following analysis.

5 APPLICABILITY OF ELECTRIC CARS

The basic limitation on the applicability of electric cars is their daily range capability. A limited-range car is not really applicable to the needs of a driver if it frequently cannot go as far as he might wish during a single day. On the other hand, it is not necessary to insist that the electric be able to do anything that its gasoline counterpart might, nor satisfy all a driver's needs on every day of his life. Any compromise definition of applicability is, of course, arbitrary, but it seems safe to say that applicability will require adequate range for the great majority of the driver's travel days.

In the study, capability adequate for 95 percent of driving days has been adopted as a definition of applicability. Figure 4.2 shows that under this definition, the "advanced-battery" cars are applicable to the needs of drivers in general, 98 percent of whom travel less than the cars' ranges on a typical day. Furthermore, these cars are applicable to the needs of two drivers sharing a single car at a household. The "lead-acid battery" cars, on the other hand, are not applicable under this definition to the travel of the average driver.

Despite its range limitation, the four-passenger lead-acid battery car is applicable to the role of second car in a two-car household, so long as the second car is defined to be that car used less on each day. It may be assumed that in a two-car household, the probability of long-distance travel by one car on a given day is independent of that for the other car. In this case, Fig. 5.1 shows the probability that the second car in a two-car household will be driven less than the indicated range, or that the second and third cars in a three-car household will be driven less. On 97 percent of the days, the four-passenger lead-acid battery car would be capable of the travel demanded of the lesser-used car in the two-car household. On only 91 percent of the days, however, could two of these cars perform the functions of both secondary cars in a three-car household, which falls short of the adopted applicability threshold.

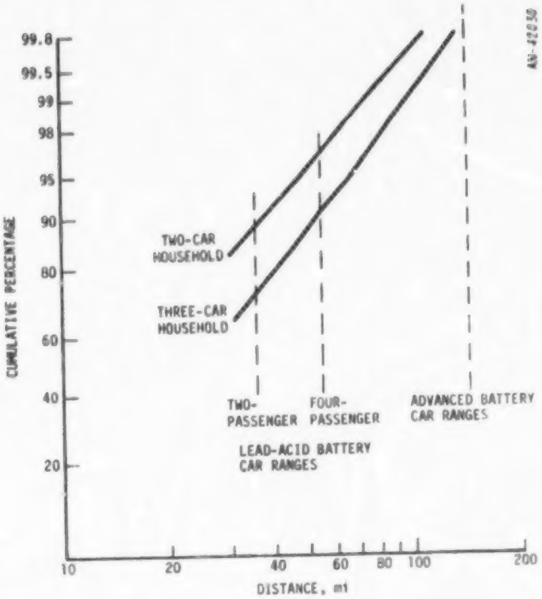

Figure 5.1. Probability of Daily Driving Less Than a Given Distance for Secondary Drivers With Cars

In practice, of course, applicability of an electric car to a driver's needs presumes overnight recharge facilities. Unless such facilities can reasonably be provided, the car cannot be considered applicable even if its range is adequate. To investigate the provision of overnight charging, the LARTS 1967 travel survey tapes were also processed to show the kinds of parking available by household type. Summary results appear in Table 5.1.

Overall, only 74 percent of cars in 1967 had off-street parking. Cars parked overnight on the street are obviously poor candidates for recharge, which requires electric power at levels usually met only from 220-volt outlets. Where the electric car is to be one of several cars at a household, however, all that is necessary is that the household have at least one off-street parking space, and a larger number of households--87 percent--fall in this category. Not every off-street parking space, however, is equally amenable to recharge; in multi-family residences with large parking lots, provision of 220-volt, individually metered outlets for recharging could be a significant problem.

TABLE 5.1

SURVEY AVAILABILITY OF PARKING, LOS ANGELES AREA

Percent of All Area Households with Off-Street Parking	
1-Car Households	38%
Multi-Car Households	49%
Total	87%
Percent of All Area Cars with Off-Street Parking	
At 1-Car Households	22%
At Multi-Car Households	52%
Total	74%
Percent of Single-Family Dwellings with Off-Street Parking	89%
Percent of Other Dwellings with Off-Street Parking	83%

Accordi[illegible] best candidates for electric car recharging are single-family hou[illegible] with off-street parking. As Table 5.1 shows, about 89 percent of such dwellings have at least one off-street parking space.

The number of automobiles for which the four-passenger 1980 electric is applicable would thus be the same as the number of single-family households with two or more cars and off-street parking. To determine this number, survey results and projections by LARTS may be employed. These necessary basic data appear in Table 5.2.

To apply the data of Table 5.2, it is necessary to scale the 1990 figures to the population forecast of this study and to interpolate for specific years of concern.[10] This is done in Table 5.3. The first three lines follow from Table 5.2, and the population and number of cars already used in this study are shown in the next two lines. The remaining lines of the table show the number of single-family housing units with cars,

TABLE 5.2

DISTRIBUTIONS OF HOUSING UNITS AND CARS, LARTS AREA

	1967	1990
Total Housing Units, Thousands	3,077	4,846
Single-Family Housing Units, Thousands	1,956	2,772
With Cars	1,715	2,437
With Two or More Cars	979	1,409
Total Cars, Thousands	4,322	7,439
Cars at Single-Family Housing Units, Thousands	2,264	4,630
Population, Thousands	9,019	13,446

SOURCE: Los Angeles Regional Transportation Study, Trip Production Model Runs, Tabs 400260-4, 4005-4-7, 400603.

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and with two or more cars; and the total number of cars at single-family housing units.

According to Table 5.3, 1,140,000 single-family housing units will have more than one car by 1980 in Los Angeles. If 89 percent of these have some off-street parking, as indicated for all single-family units in Table 5.1, then electric cars will be applicable in 1980 at slightly over one million Los Angeles households. Though this implies applicability to the roles of only 17 percent of all Los Angeles automobiles in that year, it is still a very large number on an absolute basis, especially since the standards of applicability involve minimum sacrifice and inconvenience on the part of the drivers and households.

The 1990 electric car, as noted previously, is applicable to the daily travel of most drivers. Recharging problems remain, however, so applicability will still be limited to households with ready recharge

TABLE 5.3

DISTRIBUTION OF HOUSING UNITS AND CARS, SOUTH COAST AIR BASIN

	1970	1980	1990	2000
Persons Per Housing Unit	2.94	2.81	2.77	2.70
Percent of All Housing Units Which Are Single-Family Housing Units				
With Cars	55.0	52.7	50.3	47.9
With Two or More Cars	31.5	30.3	29.1	27.9
Percent of All Cars at Single-Family Housing Units	53.7	58.0	62.2	66.5
Population, Thousands	9,700	10,600	11,600	12,400
Cars, Thousands	5,060	5,880	6,730	7,600
Single-Family Housing Units, Thousands				
With Cars	1,840	1,980	2,110	2,200
With Two or More Cars	1,050	1,140	1,220	1,280
Cars at Single-Family Housing Units, Thousands	2,720	3,400	4,190	5,060

capability. In this case, single-family households are again the most promising for recharging. Assuming that 74% of cars at single-family households have off-street parking, in accord with the area-wide figure of Table 5.1, electric cars would be applicable in over three million cases in 1990, to 46 percent of all individual automobiles in the area. In the longer term, as electric cars come into general use, we may expect that recharge provisions would be made in the off-street parking provided by multi-unit buildings. Thus by the year 2000, electric cars might be applicable at all off-street parking places. If the current 74-percent rate continues to prevail, this would make electric cars applicable in 5,600,000 cases, to 74 percent of the total car population.

Once the advanced-battery cars arrive, daily range of electric cars would be so great that average daily driving of electrics would be essentially the same as average driving of cars without range limitations. Thus in 1990 and 2000, the fraction of daily vehicle miles by electric cars would be essentially equal to the fraction of electric cars in the total car population. In 1980, however, electric cars with limited ranges will constitute most of the electric car population. They can be assigned only the less-demanding day-long travel patterns, so the percentage of electric car vehicle miles in 1980 will be considerably less than that of cars in the total population.

The average usage of such cars can be approximately deduced by integrating the mileage distributions produced by the computer processing of the Los Angeles travel survey. The normalized result of this integration is shown in Fig. 5.2. The 1980 lead-acid electric car is adequate for

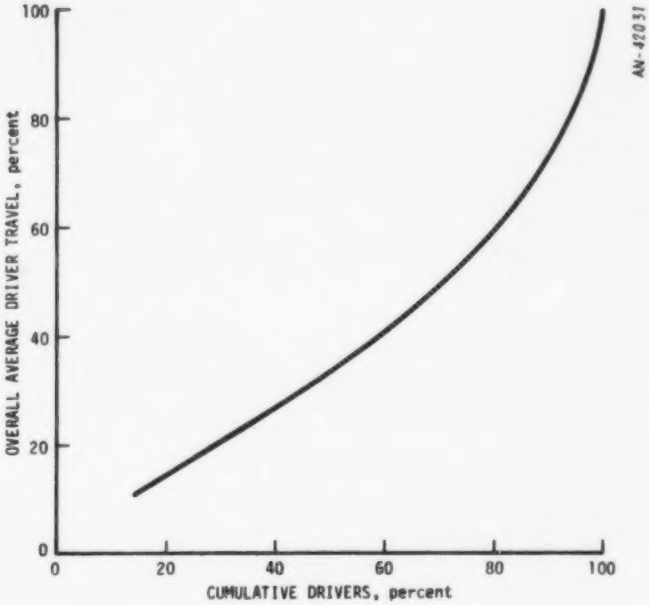

Figure 5.2. Daily Travel by Low-Travel Drivers

83 percent of drivers on a typical day. Figure 5.2 shows that the average travel mileage of that 83 percent of drivers is about 63 percent of average travel for all drivers.

This result and the previous estimates of applicability are summarized in Table 5.4.

TABLE 5.4

CANDIDATES FOR ELECTRIC CAR REPLACEMENT, SOUTH COAST AIR BASIN

	1980	1990	2000
Cars, Thousands	1,011	3,099	5,624
Percent of Total	17	46	74
Daily Vehicle Miles, Millions	18	90	169
Percent of Total	11	46	74

6 CONSUMER MARKET FOR ELECTRIC CARS

The preceding section has established the broad applicability of electric cars in Los Angeles, even with lead-acid batteries and prospective near-term technology. As early as 1980, such cars could replace over a million automobiles in Los Angeles with very small sacrifice in mobility.

This section addresses not what electric cars could do, but what the cars of Table 3.2 are likely to do in a free market operating essentially as at present--that is, a marketplace in which electric cars have not been relatively favored either by inducements to their purchase and use, or by penalties on the purchase and use of competing gasoline cars. In such a market, it is consumer preferences and perceptions which, applied to competing electric and conventional automobiles, will decide the sales and usage of the electric cars.

Unfortunately, conclusive analysis of trends and prospects in the consumer market for electric cars is not now possible. Almost no data is available which is directly applicable, since essentially no electric cars have been sold in either Los Angeles or the nation. Thus there is no avoiding major qualitative inferences in moving from existing data to sales and use estimates for the future.

This section first considers the competitive price and performance situation for future electric cars, which is generally unfavorable. Then it reviews overall market trends, which appear relatively favorable to electric automobiles. Next, it turns to relevant results of consumer surveys, which elicit consumer intentions as the best available alternative to actual observations of consumer electric-car purchases. Finally, potential free-market penetration and use estimates for the future are described.

6.1 PERFORMANCE AND PRICE COMPETITION

Because energy stored in lead-acid batteries is rather like gasoline weighing 500 pounds per gallon, electric cars must be carefully designed for energy efficiency. In consequence, as pointed out previously, electric cars in the lead-acid battery era are unlikely to be designed for acceleration and speed performance comparable to those of the conventional automobile. Moreover, electric cars promise to be more expensive initially than their conventional counterparts, and to be more expensive in total per-mile costs so long as lead-acid and nickel-zinc batteries are utilized.

On these topics--the relative importance of performance, first cost, and overall costs in determining market shares--there is a considerable body of data for existing cars. It can be reviewed to investigate whether lower performance or higher price is demonstrably detrimental to sales.

Table 6.1 presents recent performance, cost, and market data for all subcompact cars holding more than 1 percent of the market in the South Coast Air Basin of California. Performance is represented by advertised horsepower per ton of curb weight. Also shown are portions of the total US subcompact market held by each of the various entries in the table. In Fig. 6.1, market shares from this table are plotted for the most important makes and models versus horsepower per ton and versus price.

If there are any general relationships among market share, performance, and price in this data, they are certainly not obvious. Instead, review of specific figures generally raises questions which are difficult to answer. Overall, it would be exceedingly difficult to argue from this data that price and performance as measured here are the major determinants of market share.

The Vega and Pinto, for example, are similar automobiles: they cost about the same, offer about equal horsepower per ton, and are similar in appearance. Moreover, they were introduced at about the same time, both

TABLE 6.1

SALES OF 1972 SUBCOMPACT CARS

(From Ref. 1)

Make	Model	Share of Subcompact Market, Percent		Price*	Advertised Horsepower Per Ton
		South Coast Air Basin	US		
Ford	Pinto (86 hp)	15.5	11.7	2070	84
Volkswagen	Beetle/Superbeetle	14.6	16.9	1999/2249	47
Chevrolet	Vega	7.6	14.4	2060	77
Ford	Pinto Wagon	7.3	5.7	2265	72
Mazda	RX Series	5.0	2.0	2800-3100	83
Toyota	Corolla	4.9	5.1	1955-2300	75-88
Datsun	PL-510	3.6	3.4	2304-2656	90
Chevrolet	Vega Wagon	3.5	2.8	2285	67
Lincoln-Mercury	Capri 2000	3.4	2.9	2528	80
Datsun	1200	3.3	3.1	1976-2116	87
Toyota	Mark II	2.7	2.8	2310-2430	84
Ford	Pinto (54 hp)	2.3	1.7	1960	53
Toyota	Corona	2.2	2.3	2385-2532	89
Volkswagen	Fastback, Squareback	2.0	2.3	2550-2750	45
Dodge	Colt	2.0	1.6	2243-2451	79
American Motors	Gremlin	1.9	4.4	1999-2153	78-106
Toyota	Celica	1.8	1.9	2847	86
Honda	600	1.7	1.0	1473-1610	48
Buick	Opel 1900 Series	1.6	2.2	2433-2656	69
Lincoln-Mercury	Capri 2600	1.5	1.3	2821	90
Volkswagen	411 Sedan and Wagon	1.3	1.5	3280	62
Porsche	914	1.3	0.7	3900	89
Toyota	Corona	1.1	1.1	2261	92

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*Retail delivered price, exclusive of transportation charges, taxes, and accessories.

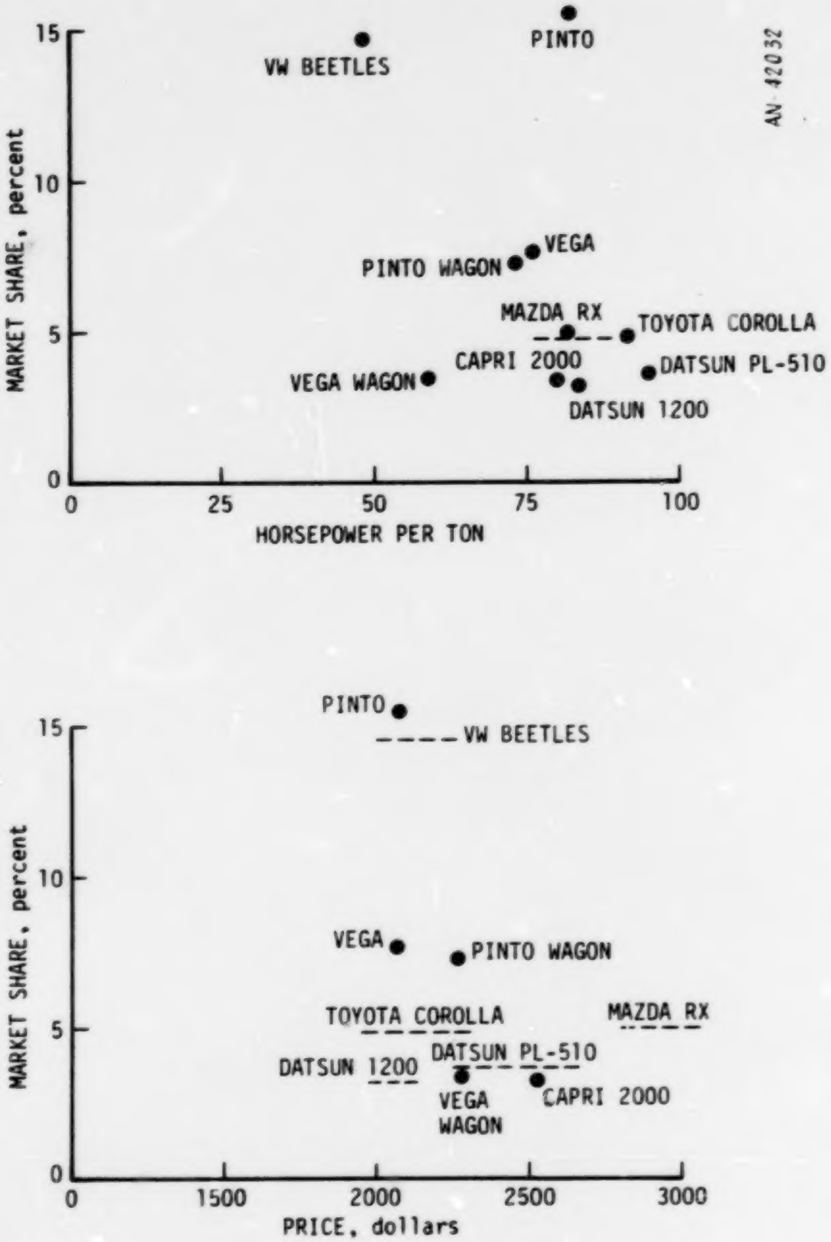

Figure 6.1. Shares of the Subcompact Market Relation to Price and Performance, South Coast Air Basin, 1972

through impressive dealer organizations, by two of the nation's (and the world's) largest corporations. One might consequently expect their sales to be approximately equal. Yet in the Los Angeles area during 1972, the Pinto outsold the Vega by a factor of 2 to 1, while nationally the Vega substantially outsold the Pinto. The determinants of these disparate market shares are by no means obvious. In any event, it is certain that in comparison with the electric four-passenger compacts, the Pinto and Vega appear virtually identical; yet their sales are very different in one direction in the South Coast Air Basin and in the opposite direction elsewhere. The necessary conclusion is that the big differences in sales between these cars must arise in relatively minor and even regional factors of consumer perception and motivation, since it is certainly not obvious in price or performance data, in general accommodations and styling offered, or in marketing muscle and expertise.

Other small mysteries are easy to find in Table 6.1. The Mazda, renowned for its performance, appears relatively ordinary in terms of advertised horsepower per ton. Perhaps this figure is no more than a poor beginning in describing performance. The American Motors Gremlin is notably less popular in the South Coast Air Basin than in the nation at large; is there something special about Los Angeles consumers, and if so, what?

In the context of Table 6.1, the four-passenger electric cars of this study are not winners in either the price or performance category. At 48 horsepower per ton, they fall near the bottom-ranked VWs; and at prices of $3,400-$7,300 (see Table 3.2) they are at or well above the range of prices in Table 6.1.[*]

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[*] As discussed in Ref. 1, the electric motor of the characterized electric cars can operate safely at 2-1/2 times its continuous-duty horsepower for short periods of acceleration. The figure of 43 hp/ton applies only to these periods. The motor controller will limit motor power input to rated levels; otherwise they might be considerably exceeded in full-throttle driving.

Nevertheless, the market position of the electric cars is by no means hopeless on these accounts. In Table 6.1, and in Fig. 6.1, the Pinto and Volkswagen Beetles stand out as top sellers, in a sales class by themselves. Their 1972 prices were similar. The Beetles, however, provided a horsepower per ton little more than half that of the Pinto. Evidently a substantial market share can be obtained despite low power and consequent minimal performance. So far as price is concerned, the Mazda suggests that unique power plants may justify a price premium approaching 50 percent. Mazda purchasers may be seeking principally flashing acceleration, but Mazda advertising has emphasized smoothness, simplicity, and reliability as much as sheer performance from a standing start. These latter advantages, of course, are commonly expected of electric propulsion in even greater measure, suggesting that modern electric cars may command higher prices in the market on that account.

6.2 OVERALL MARKET TRENDS

Much of the literature on the automobile market is concerned with total automobile sales rather than relative shares for different makes and models. Whether based on consumer surveys or sales observations, however, it clearly spells out trends generally favorable to the introduction of electric cars.

Auto sales by class have long shown declines in the market share of the larger automobiles, with a rapid rise at the subcompact end of the size, performance, and cost scales. As previous investigators have concluded, it is impractical for battery-electric cars to compete head-on with full-size automobiles, but it is possible to compete with subcompact automobiles--or at least to approach their accommodations and performance (excepting daily range). Thus consumers increasingly have come to prefer the type of automobile most amenable to electric propulsion.

Leading authorities in consumer research see elaborate related trends in consumer behavior.[12] "Studies conducted . . . in the late 1960s indicate that the car has increasingly become a means for serving important ends, rather than the highly prized possession it once was . . ." ". . . Frequently, two different types of cars were wanted. Long distance family travel--and probably also prestige, although this was rarely mentioned by survey respondents--called for the ownership of a large car. But even prestige obviously did not require that the second car be large . . ." "Interviews revealed that the major problems confronting consumers no longer concerned the car purchase itself--the make, type, or price of the car bought. Their concerns had become centered around accessories, and, more particularly, around problems that arise after the purchase . . . repairs had become a major problem, not only because of their high cost and often inconvenient timing, but also because of the difficulty in getting them done properly".

The simplicity, reliability, and minimal maintenance requirements of electric propulsion[4] should make electric cars increasingly more desirable as these trends persist. In addition, the electric car can offer a unique advantage which the conventional subcompact cannot: through its novelty and its high social desirability in fighting pollution, it can be a prestige car despite its modest dimensions.

Particularly in the Los Angeles region, prospects are favorable for small and novel automobiles. The Los Angeles area has been half a decade ahead of the nation in adopting the subcompact and the imported car: in 1972, subcompacts had almost 35 percent of the Los Angeles auto market as compared with little over 20 percent nationally.[13] Moreover, in Los Angeles the air pollution problem has long been acute and interest in minimizing pollution is high.

6.3 CURRENT SURVEYS OF MARKET POTENTIAL

There have been two recent surveys of consumer buying inclinations regarding electric cars. Consumer intentions are not always reliable, of course, and where the product is not presently in the market or well-known to the consumer, the hazards are obvious. Nevertheless, in the absence of sales data in which true consumer preference is revealed, reported intentions are an expedient indication of the sales potential of electric cars.

Investigators at the University of Wisconsin-Whitewater made a consumer survey specifically related to electric car purchase in mid-1973.[14] The extent and location of consumer interviews are shown in Table 6.2. The surveys addressed factors of importance to consumers choosing a automobile, with rank order results as indicated in Table 6.3. These findings give specific support to general trends and consumer preferences already noted. In particular, they illustrate relative lack of consumer interest in capacity, size, acceleration, and speed of automobiles--precisely those attributes which once were considered to make the "family car" immune to electrification. Among factors high in rank in Table 6.3, the electric car can be as safe as other cars of its size, good in mileage or efficiency, and superb so far as maintenance and pollution are concerned; but it will be more expensive, especially so long as it must rely on lead-acid and nickel-zinc batteries.

Furthermore, of course, electric cars will have a severe range limitation until the advanced batteries become available. The consumer survey plainly brings out the importance of this problem. Table 6.4 presents a

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TABLE 6.2

ELECTRIC CAR CONSUMER SURVEYS, APRIL-MAY, 1973 (FROM REF.14)

Place	Survey Responses
Milwaukee, Wisconsin	556
Madison, Wisconsin	332
Chicago, Illinois	341
Total	1,229

TABLE 6.3

SURVEY FACTORS REPORTED IMPORTANT IN AUTO CHOICE (FROM REF.14)

Factor	Rank
Safety	1
Cost of Operation	2
Price	3
Mileage	4
Cost of Maintenance	5
Pollution	6
Ease of Maintenance	7
Passenger Capacity	8
Size	9
Acceleration	10
Luggage Capacity	11
Speed	12

description of a possible electric car offered to survey respondents. Among nine other attributes, under the label "performance" it notes a substantial range capability at different constant speeds (which tends to be unrealistically high relative to actual stop-start urban driving). Respondents were asked which of these electric car attributes they would most like to see changed, with results shown in Table 6.5. Increased range was mentioned far more frequently than any other improvement; it was followed by rechargeability, which amounts to another means of extending range. Regardless of the capability of electric cars for accomplishing daily driving, as noted in Sec. 5 of this paper, consumers may not wish to purchase cars of limited range.

In the end, it must be recognized that the consumer purchases opportunity when acquiring an automobile, regardless of actual need for long daily range. If the consumer feels it important to be able to take long

TABLE 6.4
ELECTRIC CAR DESCRIPTION IN SURVEY (FROM REF. 14)

1. Meeting 1976 safety standards.
2. Either two- or four-passenger capacity.
3. Baggage capacity of 100-200 pounds (similar to a Pinto or Vega).
4. Heater. Radio.
5. Size: Subcompact or four-seater/station wagon (hatchback)
6. Performance

at 30 mph the range is	95-100 miles
40	75-80
50	60-65
60	50-55

7. Fuel cost of 0.5 cent per mile compared to 2.5 cents per mile for an internal combustion engine (equivalent to 55 miles per gallon).
8. Batteries recharge fully overnight or to 80 percent of capacity with a special quick-charge device taking 45 minutes.
9. 1975-76 cost of $2,500 compared to Pinto/Vega cost of $3,000.

TABLE 6.5
IMPROVEMENTS MOST DESIRED IN ELECTRIC CAR (FROM REF. 14)

1.	Performance (Range)	(38%)
2.	Rechargeability	(22.4%)
3.	Size	(11.8%)
4.	Passenger Capacity	(10.4%)
5.	Baggage Capacity	(4.6%)

trips in the automobile, even though he may never do so, then limited-range electric cars will appear less attractive.

The Wisconsin surveys asked consumers to rate their intention to buy the electric car of Table 6.4, when available, on a scale from 0 to 10. The mean response was 4.5 for Milwaukee, 4.7 for Chicago, and 5.0 for Madison. Ten to 15 percent of respondents expressed zero intention to purchase such a car, while 6 to 10 percent expressed the highest intention.

This considerable interest in buying an electric car must, of course, be qualified to the extent that the car described in Table 6.4 is impractical or infeasible. Relative to the lead-acid battery car characterized in this study (see Table 3.2), the description of Table 6.4 is overoptimistic in the following respects:

- It states a purchase price substantially less, not more, than the prices of conventional subcompacts.
- It does not mention the high cost of battery depreciation, but instead cites only a very low fuel cost, with the clear implication that total operating cost will be less, not more, than that of conventional subcompacts.
- It does not mention electric car acceleration, which by implication may be taken as comparable to, not much less than, the conventional subcompacts.
- It mentions a heater but does not note that it would probably be considerably less effective than those of conventional subcompacts, or else penalize range severely.

In the other direction, the description of Table 6.4 does not mention prospective advantages of electric cars in quietness or in reduced maintenance. Nevertheless, on balance it appears that overall consumer intentions to purchase lead-acid battery cars characterized in this study might be substantially lower than determined in the Wisconsin survey.

A study of the market potential of electric cars was conducted in 1971 for the Copper Development Association and the Electric Vehicle Council of the Electric Energy Association.[7] The basis of the study was an analysis of electric car applicability which has already been discussed in Sec. 3. Overall findings of the study are reproduced here in Table 6.6, indicating the potential population of both trucks and cars, given low and high estimates of electric car capability. In the case of passenger cars, the estimates span a potential market range of 50 to 1, and are consequently so broad as to provide little specific guidance here.

In a nationwide survey of consumer interest in an electric car purchase, the Electric Vehicle Council and the Copper Development Association obtained results shown in Table 6.7.[15] An electric car with range of 150 miles (conditions unstated), speed of 40 mph, and price of $2,000 was briefly described to a representative sample of over 2,000 interviewees, who were finally asked whether they would be interested in purchasing such a car. The results show, as did the Wisconsin survey, a large minority interested in purchasing the electric car, with interest concentrated among those having high income, education, and family car ownership, and professional or managerial occupations.

TABLE 6.6

POTENTIAL US ELECTRIC VEHICLE POPULATION

(From Ref. 7)

	Thousands of Vehicles			
	Light Trucks		Passenger Cars	
Year	Low	High	Low	High
1970	37	534	427	20,000
1975	45	661	523	24,600

TABLE 6.7

INTEREST IN ELECTRIC CAR PURCHASE, MARCH-APRIL 1972 (FROM REF. 15)

(150 mi range, 40 mph speed, $2,000)

	Yes	No	No Opinion
Total US Public	42%	52%	6%
No Car	41	46	13
One Car	39	54	7
Two Cars	46	50	4
High School Incomplete	34	57	9
High School Complete	41	56	3
Some College	59	35	6
Under $5,000 Family Income	35	55	10
$5,000-$6,999	38	57	5
$7,000-$9,999	40	54	6
$10,000-$14,999	47	49	4
$15,000 or Over	52	44	4

The Winconsin investigators proceeded from their consumer survey to estimates of the consumer market for electric vehicles.[16] They concluded that the "primary prospect is an urbanite who owns a 'new' second car, earns $10,000, and may have some college education . . . there are some 700,000 households in the US that meet these criteria." They also identified a miscellaneous secondary market among non-owners of cars, rural households, and multiple electric car households, and a major secondary market among urban owners of older second cars and urban single car households. The total potential market and an annual sales potential for an assumed replacement period are shown for these and industrial/institutional markets in Table 6.8. For lack of complete data, the annual potential is necessarily a subjective estimate.

TABLE 6.8

ESTIMATED NATIONAL POTENTIAL MARKET FOR ELECTRIC CARS IN 1974

(From Ref. 16)

	Potential Market, Thousands				
	Total		Replacement Period, Yrs	Annual	
	Low	High		Low	High
Consumers					
Primary	500	700	2	250	350
Miscellaneous Secondary	200	400	4	50	100
Major Secondary	600	1,400	4	150	300
Industrial-Institutional					
Fleet	210	300	3	70	100
Non-Fleet	90	210	3	30	70
Total	1,600	3,010		550	920

To translate market potential into estimated market penetration by year, percentage penetrations were subjectively estimated and applied by the Wisconsin investigators. The results are shown in Table 6.9 for the years 1975 through 1980. Also shown in Table 6.9 are percentage penetrations of an assumed total car market growing at the rate previously projected in this study for Los Angeles.

By 1980, the Wisconsin estimate expects 1- to 2-percent penetration of the electric car into the car market. If this prevailed in the Los Angeles area, it would amount to some 5,000 to 10,000 electric cars sold annually. As noted earlier, these figures may be high owing to the optimism of the electric car description.

TABLE 6.9

ESTIMATED NATIONAL MARKET PENETRATION OF ELECTRIC CARS TO 1980

(From Ref. 16)

Year	Annual Potential Market, Thousands		Market Penetration			Penetration of Total Car Market, Percent	
			Percent	Thousands			
	Low	High		Low	High	Low	High
1975	600	1000	1.0	6	10	0.06	0.1
1976	650	1100	1.5	10	17	0.1	0.16
1977	700	1200	2.5	15	30	0.14	0.27
1978	750	1300	5.0	38	65	0.33	0.57
1978	825	1450	10.0	83	145	0.70	1.2
1980	925	1640	15.0	139	246	1.1	2.0

6.4 ESTIMATED MARKET POTENTIAL IN LOS ANGELES

Despite the many difficulties, this study requires projections of potential electric car market penetration and use for the Los Angeles area. In this section, the basic factors involved are summarized and projections then offered. Because both the circumstances and the electric cars of this study differ from those of previous work summarized already, it is inappropriate simply to use the results of others directly.

The electric cars characterized in this study differ from those of previous consumer surveys and market estimates, at least for the next decade, primarily in two respects: their costs are substantially higher, and their range in urban driving is less than that stated or implied previously. The circumstances surrounding previous projections are not clearly defined, but in the Wisconsin work at least, conventional car costs are apparently anticipated to be somewhat higher than electric car costs.

The baseline projections and forecasts of this study are based on the explicit assumption that there is not to be a major disruption in established economic and social patterns. Analyses in the areas of population, transportation, energy, and the environment all support this assumption, in that they bring forth no evidence that there must be some such major change as gasoline rationing or restriction of electric power supply and demand. Generally, the lower population growth foreseen in the study baseline lessens prospective pressure on energy supplies, on transportation facilities, and on pollution control arrangements. Major improvements are in store, and are already in progress, in the average miles per gallon of US automobiles, which will probably reduce the total annual consumption of gasoline in Los Angeles until near the end of this century. At the same time, market prices for "new" petroleum are now higher than those found to be adequate for calling forth major increases in domestic drilling and probable discovery rates, regardless of what happens internationally. The air pollution which has plagued Los Angeles more than any other city will be substantially reduced in 15 years, after sufficient cars meeting 1977 emission standards replace the dirtier cars now being produced and operated in the Air Basin. Planned electric power plants will be adequate not only to meet additional growth at a substantial--though reduced--rate, but provide enormous unused capacity in off-peak hours and seasons.

Despite the 1974 "crisis" in energy supply, in short, despite vexing pollution problems, and despite occasional electricity blackouts, there is no necessity nor even compelling basis for presuming that such conditions need persist through the remainder of the century in the Los Angeles area. In consequence, the baseline projections of this study do not describe a future in which electric automobiles are assured supremacy by a succession of natural and economic disasters for the conventional automobile.

The electric car has some significant advantages. It promises to be reasonably efficient and low-polluting, and it is certainly novel, all of which may well make it a potent prestige and status symbol. These are psychic benefits, however, and though they may be important, they need not overshadow the more tangible major benefit of the electric: its prospective high reliability and minimum maintenance.[14] Its simplicity, the long mean times between failure of its motor and controller, and the minimal need for routine maintenance, all promise the electric motorist an end to service hassles. Quite apart from the status value, an electric car which might ordinarily require only a simple lubrication and inspection once a year could have wide appeal.

Allied against these advantages are the higher costs of electric cars relative to conventional cars and the limited daily range which they afford. Even if their reduced performance and accommodations are not deterrent to would-be purchasers, their higher initial and operating costs are sure to work against them. Moreover, consumers have already expressed their dissatisfaction with limited range. Both range and price drawbacks are projected to be reduced with the advent of zinc-chlorine and lithium-sulfur battery technology after 1985; nevertheless, they will still be at a substantial handicap. An initial cost disadvantage will remain, and though the advanced batteries may permit daily ranges far in excess of those required 99 percent of the time in urban driving, they will still not permit every trip of which conventional vehicles are capable. Particularly for family vacations and longer recreational trips, the range limitation will deter buyers.

The balancing of these advantages and disadvantages must now be completed subjectively, for lack of additional substantial evidence on consumer behavior.

The initial cost of electric cars characterized in this study, shown in 1973 dollars in Table 3.2, is substantially higher than the typical $2,270 cost of the comparable four-passenger internal-combustion subcompact.

Moreover, the total per-mile cost of the earlier electric cars (with lead-acid and nickel-zinc batteries) is likely to be 25 percent or more above the 11.6 cents per mile (in 1973 dollars) of the conventional subcompact. These combined cost disadvantages are so great that purchase by only a few percent of potential buyers seems likely: by 1980 we estimate the lead-acid battery cars will capture only 5 percent of the limited second-car market (shown in Table 6.10) for which they are reasonable candidates. The subsequent advent of advanced-battery cars with ranges adequate for general urban use will considerably expand the potential market, but the high total per-mile cost of the nickel-zinc battery car will prevent

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TABLE 6.10

POTENTIAL FREE-MARKET SALES AND USE OF ELECTRIC CARS, SOUTH COAST AIR BASIN

	1980	1990	2000
Total Car Population, thousands	5,880	6,730	7,600
Total Car Market, thousands per year	570	640	710
Candidates for Electric Car Replacement, percent	17	46	74
Electric Car Market Share			
Capture of Candidates, percent	5	10	15
Market Penetration, percent	0.9	4.6	11.1
Annual Sales, thousands	5	29	79
Electric Car Population			
Thousands of Cars	15	176	589
Percent of Total	0.26	2.6	7.8
Electric Car Use			
Daily Vehicle Miles, millions	0.27	5.1	17.8
Percent of Total	0.16	2.6	7.8

increases in the capture rate until after 1985. The zinc-chlorine battery car may then offer competitive overall costs, but its 50-percent initial cost premium and other limitations lead us to estimate an increase in the capture rate to only 10 percent by 1990. Still, with the expanded market this represents a six-fold increase in estimated sales during the decade. Modest further battery improvement in the 1990s and the further probable market expansion of that decade lead us to estimate a 15-percent capture rate, with total sales more than doubling, by the year 2000.

The implications of these estimates are shown in the top six lines of Table 6.10. The first three lines of this table recapitulate projections for total cars in the Los Angeles region, total car sales, and candidates for electrification among them, assembled from Ref. 2 and from Table 5.4. The next three lines reiterate the capture estimates just presented, and show their consequences and penetration of the total car market in the Los Angeles area.

An important assumption in this market share estimation process is that the candidates for electric car replacement are replaced at the same rate as automobiles in the total car population. This is much more conservative than the assumption of the Wisconsin investigators in Table 6.8, which anticipates a much more rapid introduction of electric cars. In the long run, however, and in the overall car population no such sales rates can be sustained, since in the car population as a whole the average replacement period is about 11 years--the life of a car.

The remaining four lines of Table 6.10 complete the projection with electric car population and use figures. The population projections assume sales growing at a linear rate during years between those called out in the table, together with the survival rates of Ref. 2, Table 6.4. The usage figures follow from resultant populations and the mileage projections of Table 5.4.

A subjective appraisal such as this is inevitably contentious. The basic questionable point is, of course, the capture percentage in Table 6.10, which was obtained by weighing primarily the high cost and limited capabilities of the electric car against its potential reliability, high status, and environmental benefit. It is certainly possible to argue that a much larger fraction of consumers would put cost and performance disadvantages second and thus buy the electric cars. Without additional solid information, however, it is surely impossible to demonstrate that the assumed capture rates of Table 6.10 are too low. We believe, in fact, that if anything they are optimistic.

It should be noted that the sales estimates of Table 6.10 simply presume that electric cars as described in Table 3.2 will be offered in the Los Angeles market. In retrospect, however, this is less than likely under free market conditions. Given a 10 percent market penetration in the year 2000 (plus similar sales elsewhere) manufacturers might well offer cars like the latter entries of Table 3.2. In earlier years, on the contrary, it seems quite unlikely that lead-acid and nickel-zinc battery cars could and would be offered at the prices of Table 3.2. Their prospective market is simply too small to support the mass-production economies implicit in these prices. Accordingly, actual sales of electric cars in Los Angeles will probably be much lower than estimated in Table 6.10, and prices substantially higher than in Table 3.2, until improvements in battery technology open prospects of capturing a significant market share.

7 UPPER-BOUND RATE OF ELECTRIC CAR INTRODUCTION

The free market penetration for electric cars represents a probable lower bound on prospective electric car use. Section 6 argues that this level of use will be quite low--too low, in fact, to obtain major benefits from automobile electrification. To capture these benefits, a public policy of electric car encouragement may be contemplated, as discussed in Sec. 8, with relative incentives tailored to achieve some higher target level of use. Before considering possible policy levels of use, it is now appropriate to establish an upper bound on levels which might reasonably be obtained.

One important factor limiting electric car use is simply the time required to start quantity production. Beyond this, it seems clearly unreasonable to seek rates of electric car introduction in excess of projected sales of conventional cars. Such rates imply that somehow or other, the Los Angeles public will be required either to scrap conventional cars earlier than normal, with attendant economic losses, or else export these cars to other regions of the country.

Typical lead times involved in bringing auto modifications to production status are shown in Fig. 7.1. This figure was derived by an impartial research organization in 1972 and is specifically applicable to 1975-1976 model years.[17] Its contents are based on extensive surveys of industry schedules and performance and thus offer a reasonable basis for present estimates. They show that about 48 months is required from the commencement of project conceptualization to production, with about 26 months required from the conclusion of vehicle preliminary design.

Given business as usual, 48 months or even more might be reasonably assumed as the minimum lead time required to bring electric cars into production, since auto electrification, even in its simplest form, is more complicated than the changes implicit in Fig. 7.1. The object of this section, however, is to project an upper bound rate of electric car introduction. This necessarily implies a situation of some urgency rather than mere "business as usual."

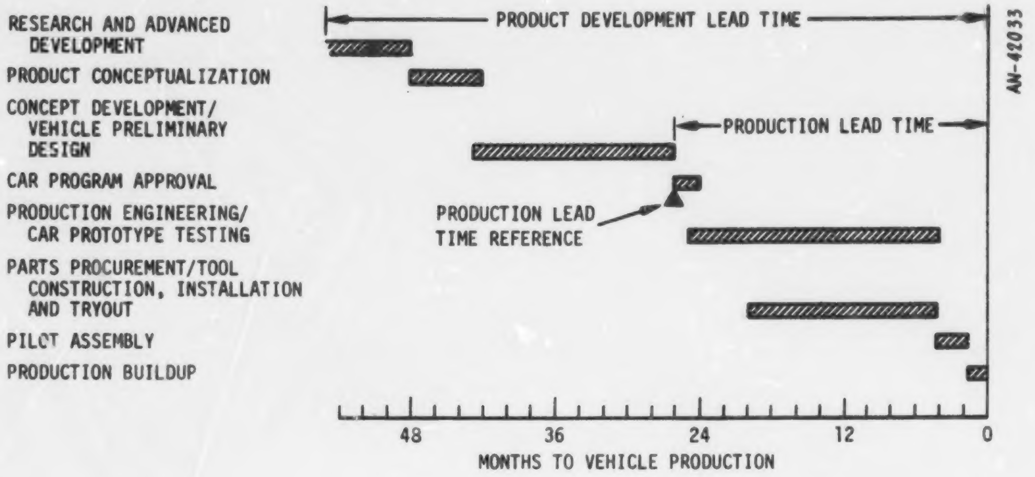

Figure 7.1. Automotive Product Development Phases (From Ref. 17)

For electric car introduction at an urgent pace, the 48-month lead time was assumed to be reduceable, primarily by shortcuts in conceptualization and preliminary design. Although the result may be less than optimum, initial electric cars can make extensive use of existing automotive assemblies, components, and production facilities. Moreover, major automobile manufacturers have already engaged in pre-production research and preliminary design for electric cars. The Ford Motor Company, for example, has an ongoing program which includes novel traction motor development.[18] General Motors built an electric minicar several years ago with particular attention to manufacturability.[19] American Motors is supplying Hornet cars to Electric Fuel Propulsion, Inc., for addition of electric traction motors, controllers, and batteries; and EFP expected to sell some 2,500 electric cars of this type during 1974.[20] It thus was assumed that a 36-month lead time to production could be achieved: the 26-month production lead time of Fig. 7.1, plus 10 months (just under half) of the usual 22-month conceptualization and preliminary design phases.

Any decision to proceed urgently with electric car introduction would require significant governmental actions which are not now in progress. Such actions could easily require years, if they were ever undertaken at all--which now appears unlikely. The purpose of this analysis, however, is not to predict what the government will do, nor how long it will take, but rather to determine the probable results of a range of possible actions. In the present instance, possible actions are to introduce electric cars in Los Angeles at various rates, and we seek to establish an upper bound on the range of rates possible.

Given an immediate decision to proceed, at the beginning of 1975, this suggests that the earliest possible quantity production would begin at the outset of 1978. Once initiated, production was assumed to rise very rapidly to capacity. Even though production rises immediately to planned levels, however, there will be only three years for electric car manufacturing before the end of 1980, the first target year of this study.

In this postulation of an upper bound, it might be reasonable to assume that electric cars could be manufactured in sufficient quantity to supply all new car sales in Los Angeles, which annually amount to some 600,000 units. This, however, seems undesirable even for the most urgent and determined public policy decision to electrify, since a substantial minority of personal transportation vehicles sold in the Los Angeles area are so specialized as to be inappropriate for replacement by electric cars. House cars, pickup trucks, off-road vehicles, and high-performance sports cars, for example, amount to well over 10 percent of the Los Angeles personal-vehicle market. Accordintly, if electric cars are sold only as replacements for new conventional passenger vehicles which would otherwise be sold, perhaps 80 percent of the projected total market might be electric.

Table 7.1 projects the results of this assumption. The first two lines of the table are projections of total car population and total

TABLE 7.1

PROJECTED MAXIMUM ELECTRIFICATION OF CARS IN SOUTH COAST AIR BASIN

	Year		
	1980	1990	2000
Total Car Population, thousands	5,880	6,730	7,600
Annual Car Sales, thousands	570	640	710
Electric Car Sales, thousands	456	512	568
Electric Car Population, thousands	1,326	4,913	6,080
Electric Cars, percent of total cars	23	73	80
Electric Car Use, percent of daily car mileage	14	73	80

annual car sales in the South Coast Air Basin from Ref. 2. At 80 percent of the annual total, electric car sales are shown in the third line of the table. Consequent electric car populations in the fourth line assume that production and sales begin at the outset of 1978 and that electric car survival rates are the same as those of conventional cars in the Basin, as developed in Ref. 2. The usage of electric cars assumes lead-acid battery cars in 1980 driven 6,500 miles per year, and advanced battery cars in 1990 and 2000 driven 10,000 miles per year, as are conventional cars. It should be noted here that a mobility loss in the early 1980s is implicit in Table 7.1. As shown in Sec. 6, the lead-acid battery car can replace, without substantial mobility loss, only about 17 percent of area automobiles, or about one million units in 1980. Thus under the assumed introduction rate, these limited-performance cars will have displaced some three hundred thousand automobiles which would have been driven significantly beyond the limited capability of the lead-acid electric. With the appearance of advanced battery cars after 1980, of course, no further mobility loss of this type will arise.

8 SCENARIOS FOR ELECTRIC CAR INTRODUCTION

The spectrum of possible electric car use in the Los Angeles region ranges between the levels of the hands-off free market situation of Sec. 6 and those of the maximum electrification pace of Sec. 7. The maximum electric car situation described in Sec. 7 would undoubtedly be economically costly and socially onerous, involving major economic transients and significant limitations of area mobility. The free market situation of Sec. 6, however, promises so low a level of electric car use that beneficial impacts could at best be minor on a regional scale, even in the year 2000. The desirability of intermediate levels of use will be appraised fully in the concluding phase of this electric car impact study. Meanwhile, it is worth noting that there are important rationales for intervention in the free-market situation to raise electric car use above the free-market case towards the maximum projection. The free market transactions, after all, now neglect almost entirely such externalities as air pollution, noise, and other automotive degradation of the urban environment. Moreover, so long as substantial governmental control is being exercised to hold energy prices down, the energy conservation issues may also be externalized in some degree. In the long run, finally, the most important benefit of electric cars could be to end the dependence of US personal transportation on imported petroleum and the political machinations of producing nations.

In this section, specific intermediate levels of use are considered which might be sought as a matter of public policy. Next, various implementation measures which might produce them are investigated. Then various dimensions of uncertainty are reviewed. Finally, specific scenarios for arriving at intermediate usage levels are hypothesized.

8.1 INTERMEDIATE LEVELS OF USE

A "high use" public policy for electric cars in Los Angeles should probably be tailored to avoid the near-term economic transients and mobility losses already noted for the maximum usage projection in Sec. 7. These ends can be accomplished simultaneously if the usage target is held to the market potentials developed in Sec. 5. Thus until 1980, the objective would be limited to capturing the second car market at single family households with off-street parking. The total population of such cars is 17 percent of all cars in Los Angeles. In the long run, then 17 percent of area sales is the maximum sustainable rate for the electric cars capable of no other functions, and presumably it would be unwise to develop manufacturing capability in excess of the long-term potential. Thus the initialization of the high-use policy might be production and sales in 1978 and subsequent years of 17 percent of projected total car sales. By 1990 and 2000, the more-capable advanced-battery cars could replace 46 percent and 75 percent of area cars. On the same line of reasoning, production of these cars should be built up during the 1980s to these fractions of the area new-car sales projections. Relative to the upper-bound projection, the overall result would be relatively little economic dislocation and mobility loss, primarily since early emphasis on lead-acid battery cars would be very much reduced.

A "medium use" policy might reasonably seek a level half-way between the high use case and the free market case. Since the free market usage is very low, this is effectively equivalent to seeking half the usage sought by the high use policy.

Projected market shares, populations, and usages of electric cars under these policies are shown in Table 8.1, together with the upper and lower bounds represented by the upper bound case and the free market case. Again, survival rates of Ref. 2 and linear growth in sales between years tabulated are assumed.

Alternative electric car populations relative to the total for the South Coast Air Basin are illustrated in Fig. 8.1. The figure makes clear that the high-use policy differs most from the upper bound during the coming decade, and thereafter approaches this bound as the higher performance electric cars come into service.

TABLE 8.1

ALTERNATIVE PROJECTIONS OF ELECTRIC CAR MARKET SHARE, POPULATION, AND USE, SOUTH COAST AIR BASIN

	Year		
	1980	1990	2000
Market Share, percent			
Upper Bound	80	80	80
High Use Policy	17	46	74
Moderate Use Policy	8.5	23	37
Free Market	0.9	4.6	11.1
Total Population, percent			
Upper Bound	23	73	80
High Use Policy	4.9	31	60
Moderate Use Policy	2.5	15	30
Free Market	0.26	2.6	7.8
Total Vehicle Miles, percent			
Upper Bound	14	73	80
High Use Policy	3.1	31	60
Moderate Use Policy	1.5	15	30
Free Market	0.16	2.6	7.8

8.2 IMPLEMENTATION MEASURES

It remains to investigate legislative and regulatory measures which might suffice to implement the high and medium use policies of Table 8.1 and Fig. 8.1. This is not a policy study, so no lengthy analysis is appropriate here. Moreover, recent work in this field has yet to establish quantitative models of the effects of various possible actions on either car use in general, or electric car use in particular, so the discussion must ultimately rest on qualitative judgments.

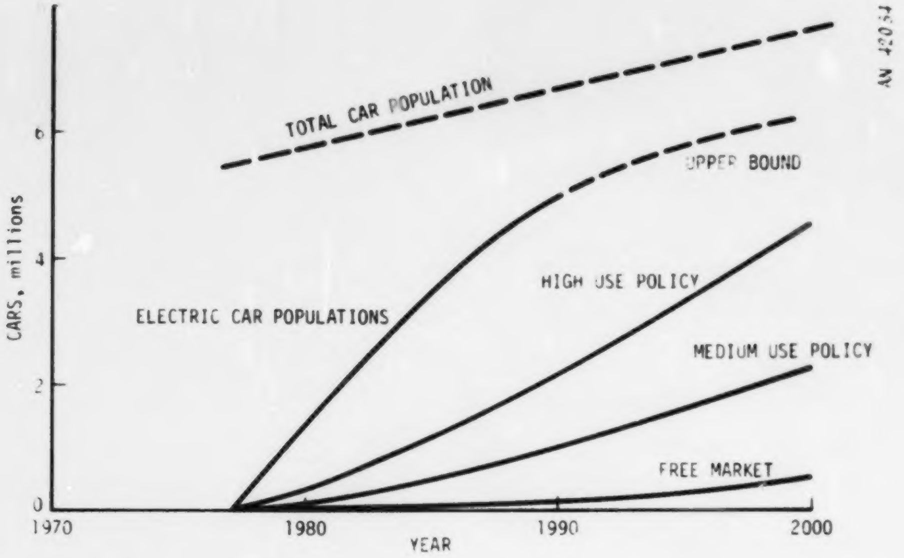

Figure 8.1. Alternative Electric Car Population Projections, South Coast Air Basin

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Electric car usage may be encouraged either by direct incentives, or by disincentives applied to the competing conventional cars. In the interests of air quality and petroleum conservation, a great many tactics in the latter category have been proposed recently. They include gasoline rationing, additional gasoline taxes, auto excise taxes, parking restrictions and price increase, restrictions on the use of roadways, and restrictions on the entry of automobiles into particular urban areas. Gasoline rationing and taxes automatically differentiate in favor of the electric car; the other measures would favor electric cars only to the extent that they were applied solely to conventional cars.

Each of these measures has advantages and disadvantages. Generally, a preferred combination of measures would achieve the desired electric car usage primarily through the price system as modified by direct user taxation, since this maximizes individual freedom of choice. Very large direct taxes, however, may be undesirable in their immediate effect on the distribution of income, since they particularly impact the poor unless and until compensating changes are introduced in our systems of welfare and progressive income taxation. Very large taxes may also be impractical in that they are highly conducive to black markets and a host of both technological and institutional dodges. Where such taxes arise, various subsidies or direct regulation of car usage deserve consideration.

8.3 GASOLINE AND LICENSE FEE SURCHARGES

To illustrate the sort of taxation which might be required to produce high electric car use, surcharges on gaoline and annual licensing will now be considered. Gasoline taxes are advantageous in that the mechanism for their collection already exists and functions smoothly. Moreover, they tend to spread disincentives to gasoline-powered cars proportional to their use. Problems would certainly develop, of course, in preventing supplies of untaxed gasoline from entering the South Coast Air Basin, if local taxes were at very high levels. The annual license fee surcharge might be simpler to enforce, but has the disadvantage of being insensitive to the different usages of individual cars.

Estimation of the order of magnitude of surcharges required to encourage high electric car use begins at relative car costs as suggested in Table 3.2. On this basis, we may develop surcharges required to put gasoline-powered cars at specific cost disadvantages relative to alternative electric cars. Finally, we may speculate on the magnitude of these cost disadvantages required to bring about desired levels of electric car use.

Tables 8.2 and 8.3 elaborate the extra initial and overall operating costs of electric cars shown in Table 3.2.[4] Table 8.2 distinguishes that part of extra initial cost required to purchase the car battery, which generally depreciates considerably faster than the car itself. Table 8.3 shows extra total per-mile operating costs of electric cars at two different gasoline prices, as detailed in Ref. 4.

TABLE 8.2

EXTRA INITIAL COSTS OF ELECTRIC SUBCOMPACT CARS (from Ref. 4)

Car Battery Type	Extra Initial Cost, 1973 dollars[*] Without Battery	 With Battery
Lead-Acid	$707	$1,907
Nickel-Zinc	675	3,615
Zinc-Chlorine	621	1,221
Lithium-Sulfur	525	1,125

---

[*] Relative to conventional subcompact costing $2270.

TABLE 8.3

EXTRA LIFE-CYCLE COSTS OF ELECTRIC SUBCOMPACT CARS (from Ref. 4)

Car Battery Type	Extra Per-Mile Cost, 1973 Dollars[*] For Gasoline at 50¢/gal[**]	 For Gasoline at 80¢/gal[**]
Lead-Acid		
Best Life	$0.027	$0.012
Worst Life	0.085	0.070
Nickel-Zinc	0.047	0.032
Zinc-Chlorine	-0.014	-0.029
Lithium-Sulfur		
Best Life	-0.011	-0.026
Worst Life	-0.002	-0.017

---

[*] Relative to conventional subcompact with total life-cycle costs per mile (including financing) of $0.133 to $0.148 (for gasoline at 50 to 80 cents per gallon, including taxes, and fuel economy of 21.4 mpg).

[**] Including taxes.

Given the basic operating cost differentials of Table 8.3 with gasoline at 50 cents per gallon, Table 8.4 shows total extra cost per 30-mile driving day. Since 30 miles is approximately the distance the conventional subcompact car could be driven on a gallon of gas,[2] figures in Table 8.4 approximate the gasoline tax per gallon which would equalize total costs of electric and conventional cars. Furthermore, since 30 miles is about the average daily driving distance in Los Angeles, figures in Table 8.4 may also be regarded as the extra daily costs which would have to be added to conventional subcompact costs for equalization with electric car costs, as might be accomplished by differential parking fees.

Simple equalization, of course, is probably insufficient to insure wide use of electric cars. Even if costs were made equal, electric cars might remain relatively unpopular because of their limited range and limited performance, despite their advantages in reduced maintenance

TABLE 8.4

EXTRA TOTAL COSTS OF ELECTRIC SUBCOMPACT*

Car Type	Total Extra Cost Per 30-Mile Day
Lead-Acid	$0.81
Best Life	$0.81
Worst Life	2.55
Nickel-Zinc	1.41
Zinc-Chlorine	-0.42
Lithium-Sulfur	
Best Life	-0.33
Worst Life	-0.03

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*See notes to Tables 8.2 and 8.3.

burdens. Chances are that a substantial cost saving must be arranged for the electric cars to insure popularity. Figure 8.2 shows surcharges on subcompact ICE cars which would produce cost disadvantages of 0 to 50 percent relative to electric cars characterized in this study. The surcharges are stated in dollars per gallon of gasoline and in dollars of additional annual license fee. If cost disadvantages of 30 to 50 percent should be necessary to produce the high level of electric car use summarized in Fig. 8.1, then these surcharges are truly enormous for the lead-acid and nickel-zinc battery cars: approximately $3 to $5 per gallon of gasoline or $1,000 to $1,800 of annual fee. For the lithium-sulfur and zinc-chlorine battery cars, much smaller surcharges would be indicated, assuming the low battery cost goals of developers are achieved, but they would still be considerable: roughly $1 per gallon of gasoline, or $360 per year.

We have no data available to pinpoint the cost differential required to obtain a specific level of electric car sales and usage. In Sec. 6.1, however, it was pointed out that relatively minor differences in conventional car characteristics apparently account for large differences in selling prices acceptable to the consumer. This suggests that the required level of surcharge in Fig. 8.2 would fall towards the high end rather than the low end of the scale.

Before leaving the dramatic surcharges of Fig. 8.2, we must briefly review the major uncertainties in electric car costs underlying these surcharges, as developed in Refs. 4 and 1. In their entirety, they convey considerably more about ranges of uncertainty and relative levels of uncertainty than does Fig. 8.2.

In Fig. 8.2, a broad range of surcharge is shown for the lead-acid electric car, despite its similarity to widely-used and relatively well-understood electric vehicle technology. In this case, most of the surcharge is attributable to battery depreciation, which depends in turn on three uncertain quantities: first, battery energy density (and hence weight and cost); second, battery initial cost; and third, battery cycle life in

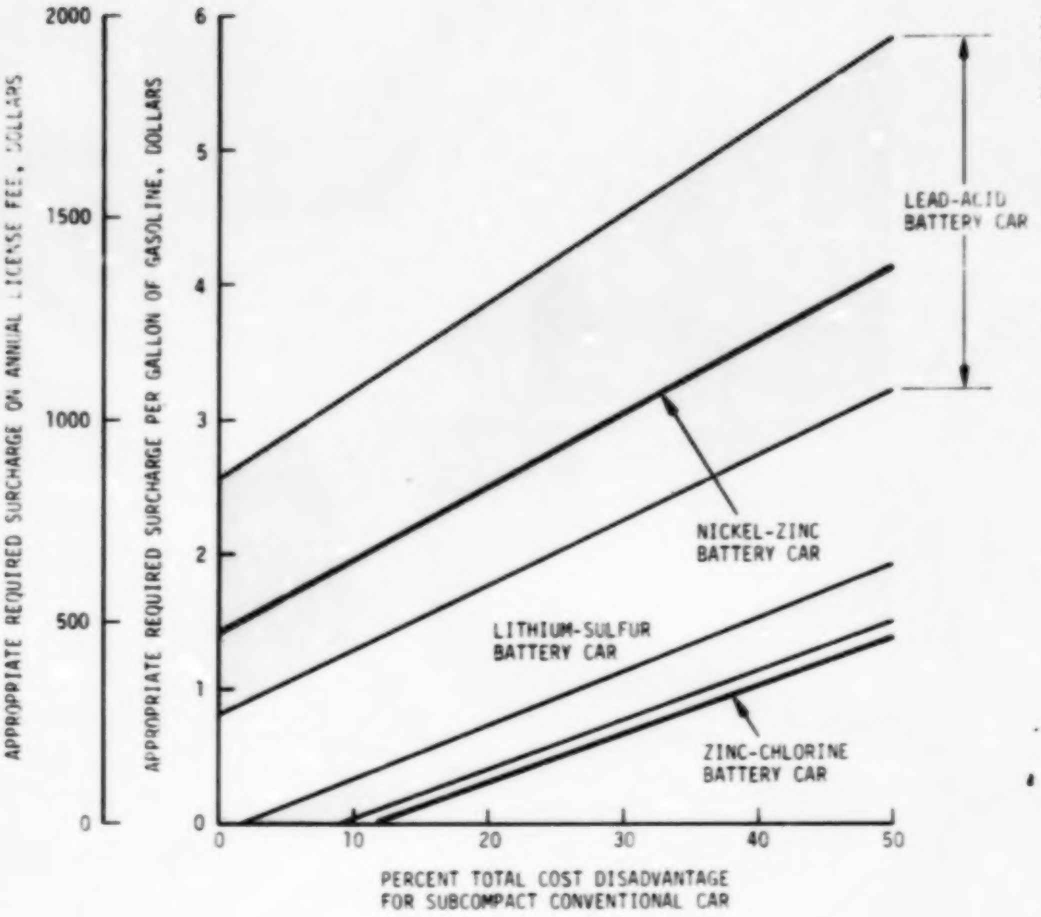


Figure 8.2. Required Surcharges to Establish Subcompact Conventional Car Cost Disadvantage Relative to Electric Cars

automotive use. Among these factors, the third is by far the most important in its effects on cost uncertainty, followed by the first. Reference 1, for example, indicates a 3-to-1 range of uncertainty in cycle life (at 65 percent discharge depth) for the lead-acid electric vehicle battery characterized for 1980. The lower life figure is that attained by currently-marketed electric vehicle batteries of similar energy density, so the upper surcharge area shaded in Fig. 8.2 is relatively certain of attainment. Considerable improvements over existing technology are implicit, however, in the lower surcharge range, and these are relatively less certain, despite the long experience we have had with lead-acid battery technology.

For the nickel-zinc battery car surcharge in Fig. 8.2, no range of uncertainty is indicated. This, however, is because little experience and data are at hand: barely enough, in fact, to arrive at the nominal battery life, depreciation, and surcharge projections subsumed in Fig. 8.2. On the one hand, "adequate" cycle life has long been the principal obstacle to nickel-zinc battery development and application. On the other hand, current laboratory data suggest that lifetimes several times greater than that implicit in Fig. 8.2 may be achieved. Thus at least as wide a range of uncertainty should be associated with the nickel-zinc battery car in Fig. 8.2 as with the lead-acid battery car.

For the other two battery cars of Fig. 8.2, risks and uncertainties are almost certainly greater still, since even less laboratory data and achievement than in the nickel-zinc case stands behind their technologies. The nominal surcharges in Fig. 8.2 for these cases are based on performance goals established and sought by their respective developers. There is relatively little basis on which to establish these goals as realistic, rather than merely wishful thinking. In these cases, moreover, initial cost may be relatively more important as a source of uncertainty. Both of these advanced batteries are relatively far from production, so associated costs are difficult to establish at present. In both cases, initial costs estimated by the developer are quite low, especially on a basis of energy storage capacity rather than weight. If both initial cost and cycle life estimates prove low by a factor of 2, the cost advantages of the respective cars with these batteries (see Table 8.3) could disappear. In any case, uncertainties abound and the surcharges of Fig. 8.2 seem far more likely to represent a lower bound rather than an upper bound on prospective cost differentials.

8.4 SUBSIDY OF ELECTRIC CARS

Gasoline taxes of up to $1 per gallon are certainly conceivable; they would produce gasoline prices no higher than those actually prevailing in the Spring of 1974 in Europe and Japan. Taxes above $2 per gallon, however, as the lead-acid and nickel-zinc battery cars might require to be competitive with the conventional subcompact, are surely extreme, implying major disruptions of established travel patterns if imposed. Recent data indicates, for example, that the price elasticity of gasoline is lower than previously estimated, nearer 0.2 than 0.3.[22] This means that a 50-cent (100 percent) increase in gasoline price might cause a 20-percent drop in consumption--and auto usage. But a $2 per gallon added gasoline tax represents a 400-percent increase from a price of 50 cents, which extrapolates to an 80-percent decline in auto travel. This extrapolation is unrealistic, of course, but its size clearly suggests that whatever the real figure, a 400-percent price increase spells major disruption of auto travel--and of the owner's budget as well.

In consequence, the imposition of tax penalties on conventional cars to encourage lead-acid and nickel-zinc battery car use appears undesirable. Alternatively, means might be found to subsidize electric car travel. If the cost to the consumer were reduced from the 15 to 20 cents-per-mile range to 8 to 10 cents-per-mile by subsidy, then the needed cost advantage to ensure electric car use might be less painfully achieved. If necessary funds were obtained from general revenues, the costs to consumers would not be intolerably concentrated in the transportation sector, with resultant non-optimum suppression of travel demand.

Various mechanisms for this are at hand: programs of aid to battery makers and electric car makers, reduction of road user taxes and fees, elimination of relevant sales taxes, and so on. Particularly where small numbers of electric cars are envisioned, as in 1980, this subsidy approach seems less objectional than conventional-car tax disincentives.

8.5 DIRECT TRAVEL RESTRICTIONS

If direct restrictions on roadway use are to encourage electric car use, they might begin by setting aside freeway and arterial lanes, not only for busses and car pools as now proposed in Los Angeles, but for electric cars as well. Under this arrangement, the value of time lost in travel due to congestion might be expected to approach the surcharges of Fig. 8.2. A study of motorist behavior in 1967 showed that motorists then were willing to pay $2.80 in tolls to save an hour of travel.[23] This suggests that the current value of motorists' time is $4 to $5 per hour, depending largely on whether increases in average hourly income or the consumer price index are taken as the basis of adjustment. From Fig. 3.1, the average Los Angeles home-to-work trip will require around 15 minutes, and traverse some 8 miles at the travel speeds of Table 3.1. For the lead-acid and nickel-zinc battery car, the required surcharge on 8 miles is 30 to 80 cents, equivalent to 4 to 12 minutes at the $4.00 per hour rate. Thus equalization of the electric car costs would require lane restrictions imposed on conventional cars which would increase their travel time from 25 to 100 percent.

In the first approximation, the costs of roadway restrictions are equivalent to those of the other means discussed for eliminating the electric car disadvantage. Other factors, however, make such travel restrictions undesirable in comparison with direct taxation and subsidy. If congestion delays are increased to this extent, conventional cars will be forced into extended stop-and-go driving on both streets and freeways. Although the result may lend relative encouragement to electric cars, it will also substantially increase pollutant emissions by the conventional cars and at the same time will considerably increase their energy consumption per mile.

Another regulatory alternative, restrictions on entry of gasoline cars into certain urban areas at certain times, could potentially generate equally serious side effects. One would be differential penalization of area businesses, to their serious detriment. Another would be economic inefficiency arising as households acquired more cars than necessary: electric cars to use in restricted areas at restricted times, and conventional cars for use at other times and places.

8.6 SCENARIOS FOR ELECTRIC CAR INTRODUCTION

The policy levels of use developed in Sec. 8.1 and displayed in Fig. 8.1 were constructed with only a preliminary regard for the phasing-in of consecutive developments in electric car battery technology. This is, of course, an oversimplification; as Sec. 8.3 details, there are very large disparities in dollar costs and in uncertainties among the battery technologies. In consequence, the usage buildups of Fig. 8.1 are inappropriate themselves as scenarios for electric car introduction, since high usage in 1980 could be as undesirable as it might be desirable by the year 1990 or 2000, when the high-cost battery technologies will hopefully have given way to lower-cost technologies.

Accordingly, schedules for introducing single electric car technologies must be hypothesized here. This will provide pure, elemental cases for impact assessment and evaluation at the conclusion of the overall study which this usage analysis supports. Only on the basis of these assessments will a construction of complete scenarios, integrated from the elemental pieces, be productive.

Overall, the objective here must be to define scenario elements using pure technologies which may be combined as needed to obtain moderate and high levels of use as shown in Fig. 8.1. In each case, of course, these scenario elements must comply with constraints implicit in

Fig. 8.1; i.e., they must begin sales of electric cars no earlier than the availability of the corresponding battery technology, and they must not exceed the market shares appropriate to prospective car applicability.

A set of such scenario elements is presented in Table 8.5. It includes the most interesting cases for impact evaluation, and complies fully with the appropriate constraints.

In 1980, only lead-acid battery technology will have been available for any length of time, and only 5 percent of cars may reasonably be electrified in the available time. This corresponds to a high-use case which is itself so modest that consideration and evaluation of a "moderate" use case would involve trivial electric car use and impacts, so no "moderate" use case is included. The market share required here, deduced from the auto age distribution of Ref. 2, is within the 17% upper limit of Sec. 8.1.

TABLE 8.5

SCENARIO ELEMENTS FOR ELECTRIC CAR INTRODUCTION

Target Year	Use Policy	Electric Car Population Target	Battery Type	Sales Period	Approximate Average Market Share
1980	High	5%	Lead-acid	1978-1980	16%
1990	Moderate	15%	Lead-acid	1978-1990	16%
			Nickel-zinc	1980-1990	17%
			Zinc-chlorine	1985-1990	30%
	High	30%	Nickel-zinc	1980-1990	35%
2000	Moderate	30%	Zinc-chlorine	1990-2000	35%
			Lithium-sulfur	1990-2000	35%
	High	60%	Zinc-chlorine	1990-2000	70%
			Lithium-sulfur	1990-2000	70%

For 1990, all available technologies are included for moderate use, but only one is appropriate for high electric car usage. Lead-acid cars have insufficient range to replace more than 17 percent of area cars and consequently cannot support the 30 percent high usage level, whereas zinc-chlorine technology is only available for five years prior to the target year for evaluation, and could not reach the high use level without sales in excess of the 46 percent maximum assumed in Sec. 8.1. For the target year 2000, lead-acid and nickel-zinc technologies are omitted because the more advanced battery systems may achieve much lower costs and should then be much preferable. Moreover, the 1990 high-use nickel-zinc case should reveal impacts quite similar to those which would be deduced for this battery car in 2000.

A variety of combinations of these scenarios may be constructed after impact evaluation, since where two technologies are used at one time, their impacts may be simply added because the impacts are basically linear with electric car use. The range of possible combinations is very wide, since any two of the moderate use elements of Table 8.5 in a given year may be taken simultaneously to develop a high level of use in that year.

The legacy of electric cars left in a given target year from the population of the previous target year is so small that it may be dismissed. Only about 13 percent of area cars are more than 10 years old. Since each decade in Table 8.5 sees electric car populations double, the implication is that the legacy would usually be only 6 1/2 percent of the total number of electric cars under consideration, a figure smaller than other uncertainties involved in impact assessment. Accordingly, if an overall scenario is built up for electric car introduction from the elements of Table 8.5, the car population in a later target year will not substantially depend on that of a previous target year.

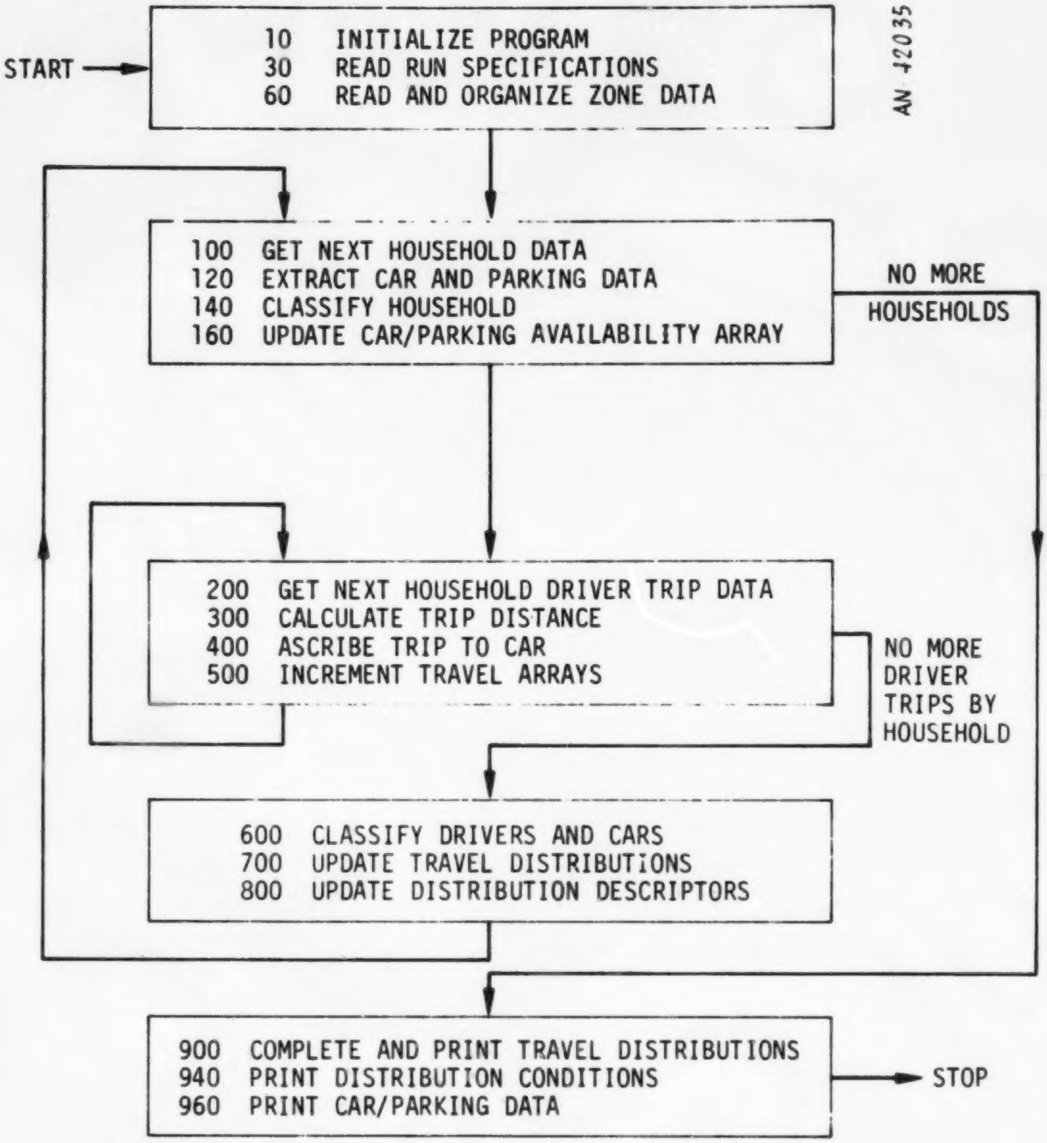
APPENDIX

COMPUTER PROCESSING OF LOS ANGELES TRANSPORTATION DATA

Data from the 1967 home-interview survey on magnetic tapes was processed by a computer program according to the logic of Fig. A.1. A listing of the program and its subprograms follows.

Most of the processing is accomplished within the main program. A separate subprogram, however, was used to process zone-node data. Identification numbers and centroid coordinates for over a thousand traffic zones were card-punched in compressed format. The subprogram read these cards and organized their zone data for easy subsequent access when it was first called. Subsequently, it referenced the data upon demand to determine zone-to-zone distances. Two other small subroutines were employed to decode BCD tape entries for processing, and to place headings on output pages.

The program listing which follows is largely self-explanatory. It contains numerous comment cards which explain functions of individual blocks of code and define most data. Numbers in Fig. A.1 are repeated as statement numbers beginning corresponding blocks of code in the program listing.


START
10 INITIALIZE PROGRAM
30 READ RUN SPECIFICATIONS
60 READ AND ORGANIZE ZONE DATA
100 GET NEXT HOUSEHOLD DATA
120 EXTRACT CAR AND PARKING DATA
140 CLASSIFY HOUSEHOLD
160 UPDATE CAR/PARKING AVAILABILITY ARRAY
NO MORE HOUSEHOLDS
200 GET NEXT HOUSEHOLD DRIVER TRIP DATA
300 CALCULATE TRIP DISTANCE
400 ASCRIBE TRIP TO CAR
500 INCREMENT TRAVEL ARRAYS
NO MORE DRIVER TRIPS BY HOUSEHOLD
600 CLASSIFY DRIVERS AND CARS
700 UPDATE TRAVEL DISTRIBUTIONS
800 UPDATE DISTRIBUTION DESCRIPTORS
900 COMPLETE AND PRINT TRAVEL DISTRIBUTIONS
940 PRINT DISTRIBUTION CONDITIONS
960 PRINT CAR/PARKING DATA
STOP

AN 42035

Figure A.1. Processing of Los Angeles 1967 Travel Survey

```
      PROGRAM AUTOUSE
C
C-----COMPUTES DISTRIBUTIONS OF DAILY CAR AND DRIVER TRAVEL FROM
C     HOUSEHOLD AND TRIP DATA TAPES OF THE LARTS 1967 HOME INTERVIEW SURVEY.
C
C     HOUSEHOLD DATA TAPE IS ON UNIT 1.  TRIP DATA TAPE IS ON UNIT 2.
C     HOUSEHOLD DATA IS IN 13-WORD RECORDS, EACH DESCRIBING A SINGLE
C     HOUSEHOLD, SORTED ACCORDING TO HOUSEHOLD ID.  TRIP DATA IS IN
C     RECORDS OF 720 WORDS, EACH DESCRIBING 36 TRIPS, ORDERED ACCORDING
C     HOUSEHOLD ID, EXCEPT A VERY FEW SHORTER RECORDS.
C
C
      COMMON KONTROL(3)
C
C     THESE ARE INPUT INTEGER PRINTOUT CONTROLS.  IF NON-ZERO, CAUSE
C     INTERMEDIATE OUTPUT FROM EACH HOUSEHOLD TAPE RECORD, EACH TRIP DATA
C     ENTRY, AND FROM INCOMPLETE DISTRIBUTIONS, RESPECTIVELY.
C
      COMMON NHOMREC,NTRPREC,NTENTRY,NPAR1,NPAR2,NGARBLE,IGARBLE,NTRIPS,
     1   NHOMSKP,NTAXTRP,NTRKTRP,NHOMIT,NOUSE,NOCARS,NOTRIPS,NOPERS,
     2   NTOMIT,NOZONE
C
C     COUNTS OF RECORDS READ FROM HOUSEHOLD TAPE AND TRIP TAPE, TRIPS
C     PROCESSED FROM CURRENT TRIP RECORD, PARITY ERRORS ON UNITS 1 AND 2,
C     TOTAL NUMBER OF GARBLES IN DATA, FLAG SET FOR CURRENT GARBLE,
C     TRIPS PROCESSED FOR CURRENT HOUSEHOLD, NUMBER OF HOUSEHOLDS
C     SKIPPED IN ATTEMPT TO MATCH CURRENT TRIP ID, NUMBER OF TAXI
C     DRIVER TRIPS SKIPPED, NUMBER OF TRUCK DRIVER TRIPS SKIPPED,
C     NUMBER OF HOUSEHOLDS SKIPPED IN TOTAL, AND NUMBER OF ONLY CARS
C     NUMBER OF HOUSEHOLDS SKIPPED IN TOTAL, NUMBER OF SKIPPED
C     HOUSEHOLDS WITH UNUSED CARS, NUMBER OF SKIPPED HOUSEHOLDS WITH
C     DRIVER TRIPS INDICATED BUT NOT FOUND ON TRIP TAPE, NUMBER
C     OF SKIPPED HOUSEHOLDS WITHOUT ANY PERSONS RESIDENT,  NUMBER OF
C     TRIPS OMITTED FOR FAULTY HOUSEHOLD ID, AND NUMBER OF TRIPS
C     OMITTED FOR BAD ZONE NAMES.
C
      COMMON K1,K2,K3,K4,K5,K11,K12,K13,K14,K15
C
C     THESE FLAGS ARE SET BY SUBROUTINE DECODER IN EXTRACTING NEEDED
C     NUMERICAL DATA FROM CURRENT HOUSEHOLD AND TRIP DATA.
C
      COMMON HOME(13),HOMID,NMONTH,NDAY,HOMTYP,NPERS,NPASSV,NPKUP,
     1 NTRIPD,NSTOP,LONGDIS,NPKG,MKTVAL,NAZ67
      INTEGER HOMTYP
C
C     CURRENT HOUSEHOLD DATA ARE STORED IN THESE VARIABLES.  THE CURRENT
C     HOUSEHOLD RECORD, VERBATIM, IS IN HOME(13).  SELECTED VARIABLES
C     EXTRACTED FROM HOME(13) ARE STORED IN THE REMAINING VARIABLES,
C     INITIALLY IN A FORMAT.
C
      COMMON HHDENT(6)
      LOGICAL HHCOL(6)
      COMMON HHDATA(6,6)
      DIMENSION HHLABL(2,6)
C
C     THIS BLOCK OF VARIABLES IS USED IN DEVELOPING OVERALL DESCRIPTORS
C     OF HOUSEHOLD DATA.  HHDENT HOLDS ONE COLUMN OF DATA TO BE ADDED TO
```

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```
C       APPROPRIATE COLUMNS OF HHDATA.  HHCOL DESIGNATES THE APPROPRIATE
C       COLUMNS.  HHLABL CONTAINS HOLLERITH LABELS FOR THE ENTRIES IN
C       HHDENT AND FOR THE ROWS OF HHDATA.
C
        COMMON TRIPS(20,36), TRIPID, PERSON, MODE, FRSWRK, BEGTIM, ENDTIM,
       1 FWY, ONITE, PKG, NPASS, NORIG, NDEST, TRPTYP
C
C       CURRENT TRIP DATA ARE STORED IN THESE VARIABLES.  TRIPS HOLDS ALL
C       36 TRIPS RECORDED IN A SINGLE RECORD ON THE TRIP TAPE.  THE
C       REMAINING VARIABLES ARE FILLED IN, INITIALLY IN A FORMAT, WITH
C       DATA FOR THE CURRENT TRIP SELECTED FROM TRIPS.
C
        COMMON TRP(10),DRIVEL(8,10),CARVEL(8,10)
        LOGICAL DRIASS(6,10),CARASS(4,10)
        COMMON DISTDIS(10,40),TRIPDIS(10,40),CONDIS(10,9)
        DIMENSION DST(41),TRIPNO(41),CONDX(9)
C
C       THESE VARIABLES ARE USED IN ACCUMULATING DRIVER AND CAR TRIP DATA
C       FOR EACH HOUSEHOLD, AND IN DEVELOPING FROM IT TRAVEL DISTRIBU-
C       TIONS FOR ALL HOUSEHOLD DRIVER TRIPS.  TRP CONTAINS KEY DESCRIP-
C       TORS OF THE CURRENT TRIP.  CONTENTS OF TRP ARE ADDED TO ROWS OF
C       THE DRIVER TRAVEL AND CAR TRAVEL ARRAYS DRIVEL AND CARVEL.  EACH
C       SUCH ROW ACCUMULATES DATA FOR TRIPS ON THE SURVEY DAY MADE BY A
C       SINGLE DRIVER OR CAR.  THE DRIVER CLASS AND CAR CLASS ARRAYS,
C       DRIASS AND CARASS, SHOW WHICH OF VARIOUS FINAL DISTRIBUTIONS AND
C       SUBDISTRIBUTIONS EACH DRIVER AND CAR BELONG TO.  THE VARIOUS TRIP
C       MILEAGE DISTRIBUTIONS ARE ACCUMULATED IN THE COLUMNS OF ARRAY
C       DISTDIS, WHILE THE TRIP NUMBER DISTRIBUTIONS ARE ACCUMULATED IN
C       ARRAY TRIPDIS.  VARIOUS DESCRIPTIVE CONDITIONS ARE ACCUMULATED
C       IN THE COLUMNS OF ARRAY CONDIS, WHICH ARE INCREMENTED FOR EACH
C       HOUSEHOLD AND ITS TRIPS BY CONDX.  DST AND TRIPNO DEFINE THE
C       CELLS OF THE DISTANCE AND TRIP NUMBER DISTRIBUTIONS, AND DST
C       SUPPLIES ROW LABELS WHEN DISTDIS IS PRINTED.
C
        DIMENSION TOTAL(20),DRVRNAM(10)
C
C       TOTAL IS A WORKING STORAGE ARRAY USED IN NORMALIZATION AND
C       CUMULATION OF THE DISTRIBUTIONS FOR FINAL PRINTOUT.
C       DRVRNAM(I) IS THE (ALPHABETIC) NAME OF THE I-TH DRIVER AT A
C       HOUSEHOLD.
C
        DATA (DST(I),I=1,41) /
       1   0.,2.,4.,6.,8.,10.,12.,14.,16.,18.,20.,22.,24.,26.,28.,30.,
       2   32.,34.,36.,38.,40.,42.,44.,46.,48.,50.,55.,60.,65.,70.,75.,
       3   80.,85.,90.,95.,100.,125.,150.,175.,200.,9999.     /
        DATA (TRIPNO(I),I=1,41)  /
       1   0.,.5,1.5,2.5,3.5,4.5,5.5,6.5,7.5,8.5,9.5,10.5,11.5,12.5,
       2   13.5,14.5,15.5,16.5,17.5,18.5,19.5,20.5,21.5,22.5,23.5,
       3   24.5,25.5,26.5,27.5,28.5,29.5,30.5,31.5,32.5,33.5,34.5,35.5,
       4   36.5,37.5,38.5,9999.  /
        DATA (CONDX(I),I=1,9)  /
       1   10HTOTAL MI  ,  10HINTRAZ MI ,  10HWKDAY MI  ,
       2   10HTOTAL TRPS,  10HINTRAZ TPS,  10HWKDAY TRPS,
       3   10HONITE TRPS,  10HEXTNL TRPS,  10HCLASS POP.    /
        DATA (HHLABL(I),I=1,12)   /
       1   20HTOTAL HOUSEHOLDS    ,  20HTOTAL CARS          ,
       2   20HPICKUP TRUCKS       ,  20HLONG-DIST VEHICLES  ,
       3   20HHOUSEHOLDS WITH PKG ,  20HCARS WITH PARKING      /
C
C-----INITIALIZE PROGRAM
```

```
C
 1     CALL HEAD(10HAUTO USAGE)
       CALL HEAD(10)
       DO 14 I=1,30
 14    KONTROL(I)=0
       NTLNTH=36
C
C-----READ RUN SPECIFICATIONS
C
 30    PRINT 32
 32    FORMAT(1X 25HRUN CONTROL PARAMETERS - //)
       DO 36 I=1,3
       READ 34, KONTROL(I)
 34    FORMAT(40H                                        I10)
 36    PRINT 34, KONTROL(I)
C
C-----READ AND ORGANIZE ZONE NAMES AND CENTROID LOCATIONS
C
 60    CALL DIST(0,0,D)
       CALL HEAD(3)
       PRINT 92
 92    FORMAT(10X 50H   HOMID    TRIPID     NAZ67    NHOMREC           /)
C
C-----GET NEXT HOUSEHOLD DATA
C
 100   BUFFER IN (1,0) (HOME(1),HOME(13))
 101   IF (UNIT,1) 101,104,900,102
 102   NPAR1=NPAR1+1
 104   NHOMREC=NHOMREC+1
       DECODE (130,106,HOME)
      1   HOMID, NMONTH, NDAY, HOMTYP, NPERS, NPASSV, NPKUP,
      2   NTRIPD, NSTOR, LONGDIS, NPKG, MKTVAL, NAZ67
 106   FORMAT(A7, 9XA2, 7XA1, 2XA1, 3XA2, 4XA1, A1, 10XA3, 24XA2, 1XA1,
      1   1XA1, A1, 13XA4)
       IF (KONTROL(1).LT.1) GO TO 120
       CALL HEAD(3)
       PRINT 108,NHOMREC
 108   FORMAT(31H DATA FROM HOUSEHOLD RECORD NO.   I5 //)
       PRINT 112
 112   FORMAT(      50H    ID        MONTH       DAY       HOME      PERSONS
      1             50H   PASS.     PICK-     DRIVER    STORIES   L-DIST
      2             30H  PARKING   MARKET      ZONE         /
      3             50H                                   TYPE
      4             50H   VEH.        UPS       TRIPS                    VEH
      5             30H               VALUE                //)
       PRINT 114,
      1   HOMID, NMONTH, NDAY, HOMTYP, NPERS, NPASSV, NPKUP,
      2   NTRIPD, NSTOR, LONGDIS, NPKG, MKTVAL, NAZ67
 114   FORMAT(  1XA8,1X    4XA2,4X    2(5XA1,4X)    4XA2,4X    2(5XA1,4X),
      1   4XA3,2X   4XA2,4X   3(5XA1,4X)  3XA4,3X )
C
C-----EXTRACT CAR AND PARKING DATA
C
 120   CALL DECODER(NPASSV,1,NPASSV,K1)
       CALL DECODER(NPKUP,1,NPKUP,K2)
       CALL DECODER(NTRIPD,3,NTRIPD,K5)
      CALL DECODER(LONGDIS,1,LONGDIS,K3)
      CALL DECODER(NPKG,1,NPKG,K4)
      CALL DECODER(NDAY,1,NDAY,KDAY)
      NCARS=NPASSV+NPKUP
      IF (NHOMREC.EQ.1.OR.HOMID.EQ.TRIPID) GO TO 140
      NHOMIT=NHOMIT+1
      NHOMSKP=NHOMSKP+1
      IF (NCARS.NE.0.AND.NTRIPD.EQ.0) NOUSE=NOUSE+1
      IF (NCARS.EQ.0) NOCARS=NOCARS+1
      IF (NTRIPD.NE.0) NOTRIPS=NOTRIPS+1
      CALL DECODER(NPERS,2,NPERS,KPERS)
      IF (NPERS.EQ.0) NOPERS=NOPERS+1
      IF (MOD(NHOMSKP,100).EQ.0) PRINT 1202,HOMID,TRIPID,NAZ67,NHOMREC
 1202 FORMAT(10X 3A10,I10)
      IF (NHOMSKP.LT.10000) GO TO 100
 121  CALL HEAD(3)
      PRINT 122, HOMID, TRIPID, NHOMREC, NTRPREC, NTENTRY
 122  FORMAT(31H HOME ID DIFFERS FROM TRIP ID -   /1H0  /
     1   1H0  10X  2A10,  3I10  )
      GO TO 900
C
C-----CLASSIFY HOUSEHOLD
C
 140  NHOMSKP=0
      HHDENT(1)=1.
      HHDENT(2)=NCARS
      HHDENT(3)=NPKUP
      HHDENT(4)=LONGDIS
      HHDENT(5)=MIN0(1,NPKG)
      HHDENT(6)=MIN0(NCARS,NPKG)
      DO 146 I=2,8
 146  HHCOL(I)=.FALSE.
      HHCOL(1)=.TRUE.
      IF (NCARS.EQ.  1)  HHCOL(2)=.TRUE.
      IF (NCARS.GT.  1)  HHCOL(3)=.TRUE.
      IF (HOMTYP.EQ.1HA)  HHCOL(4)=.TRUE.
      IF (HOMTYP.EQ.1HF)  HHCOL(5)=.TRUE.
      IF (HOMTYP.EQ.1HG)  HHCOL(6)=.TRUE.
      IF (HOMTYP.EQ.1HH)  HHCOL(7)=.TRUE.
      DO 152 I=4,7
 152  IF (HHCOL(I)) GO TO 160
      HHCOL(8)=.TRUE.
C
C-----UPDATE CAR/PARKING DATA FOR HOUSEHOLD
C
 160  DO 166 J=1,6
      DO 166 I=1,8
 166  IF (HHCOL(I)) HHDATA(I,J)=HHDATA(I,J)+HHDENT(J)
      IF (KONTROL(1).LT.2) GO TO 190
      PRINT 172
 172  FORMAT(1H0/ 34H CURRENT HOME DATA DISTRIBUTION -   / )
      PRINT 174
 174   FORMAT(30X 33(1H-) 14HHOUSEHOLD TYPE  33(1H-)  // 30X
     1   50H    ALL        1-CAR    MULTICAR   1-FAM.     DUPLEX
     2   50H  3+4PLEX      APT       OTHER                          )
      PRINT 176, ((HHLABL(I,J),I=1,2),(HHDATA(I,J),I=1,8),J=1,6)
 176  FORMAT(1X 2A10, 9X 8(F8.0,2X) )
 190  IF (NHOMREC.NE.1) GO TO 230
C
C-----GET NEXT HOUSEHOLD DRIVER TRIP DATA
C
 200  IF (NTENTRY.LT.NTLNTH.AND.NTENTRY.NE.0) GO TO 220
      NTENTRY=0
      NTRPREC=NTRPREC+1
 210  BUFFER IN (2,0) (TRIPS(1,1),TRIPS(20,36))
 211  IF (UNIT,2) 211,219,217,218
 217  ENDTRPS=1234.
      GO TO 600
 218  NPAR2=NPAR2+1
 219  NTLNTH=LENGTH(2)/20
 220  NTENTRY=NTENTRY+1
      DECODE (200,222,TRIPS(1,NTENTRY))
     1   TRIPID, PERSON, MODE, FRSWRK, BEGTIM, ENDTIM,
     2   FWY, ONITE, PKG, NPASS, NORIG, NDEST, TRPTYP
 222  FORMAT(A7, 13XA1, 46XA1, 13XA1, 1XA5, 2XA5, 2XA3, 3XA2, A1,
     1   2XA1, 24XA4, 11XA4, 37XA1  )
      IF (TRIPID.EQ.HOMID) GO TO 230
      DECODE (7,224,TRIPID) IDLTR,IDNMBR
 224  FORMAT(R1,A6)
      IF (IDLTR.GT.26) GO TO 226
      CALL DECODER(IDNMBR,6,IDNMBR,KONTENT)
      IF (KONTENT.NE.1) GO TO 226
      GO TO 600
 226  NTOMIT=NTOMIT+1
      IF (NTOMIT.LT.5000) GO TO 200
      CALL HEAD(3)
      PRINT 228,HOMID,TRIPID
 228  FORMAT(32H TRIPID IS NOT IN PROPER FORM -  /1H0  / 1H0 10X 2A10)
      GO TO 900
 230  IF (KONTROL(2).LT.1) GO TO 260
      IF (NTRIPS.EQ.0) PRINT 244
 244  FORMAT(1H0/50H    ID        PERSON     MODE      WORK       BEGIN
     1            50H    END        FWY       OVER      PARK       TOTAL
     2            30H  ORIGIN     DEST      TRIP        /
     3            50H                                 TRIP 1     TIME
     4            50H   TIME                NITE                  IN VEH.
     5            30H   ZONE       ZONE      TYPE        //)
      PRINT 246,
     1   TRIPID, PERSON, MODE, FRSWRK, BEGTIM, ENDTIM,
     2   FWY, ONITE, PKG, NPASS, NORIG, NDEST, TRPTYP
 246  FORMAT(1XA8,1X  3(5XA1,4X)  2(3XA5,2X)  4XA3,3X  4XA2,4X
     1   2(5XA1,4X)   2(3XA4,3X) 5XA1   )
 260  IF (MODE.EQ.1HB) NTAXTRP=NTAXTRP+1
      IF (MODE.EQ.1HD) NTRKTRP=NTRKTRP+1
      IF (MODE.NE.1HA.AND.MODE.NE.1HC) GO TO 200
      NTRIPS=NTRIPS+1
      DO 262 IDRVR=1,10
      IF (DRVRNAM(IDRVR).EQ.PERSON) GO TO 266
      IF (DRVRNAM(IDRVR).EQ.0.) GO TO 264
 262  CONTINUE
      IGARBLE=1
      GO TO 200
 264  DRVRNAM(IDRVR)=PERSON
 266  CALL DECODER(ONITE,2,IONITE,K12)
```

```
      IF (K12.NE.1) IONITE=0
      CALL DECODER(PKG,1,IPKG,K13)
      IF (K13.NE.1) IPKG=0
      CALL DECODER(NORIG,4,IORIG,K14)
      IF (K14.NE.1) IGARBLE=1
      CALL DECODER(NDEST,4,IDEST,K15)
      IF (K15.NE.1) IGARBLE=1
      IF (IGARBLE.NE.0) GO TO 200
C
C-----CALCULATE TRIP DISTANCE
C
 300  D=0.
      IEXT=1
      IF (IORIG.LE.1000.OR.IDEST.LE.1000) GO TO 400
      IEXT=0
      IF (IONITE.EQ.0.AND.IGARBLE.EQ.0) CALL DIST(IORIG,IDEST,D)
      IF (D.GE.0) GO TO 400
      NOZONE=NOZONE+1
      GO TO 200
C
C------ASCRIBE TRIP TO CAR
C
 400  IF (NCAPS.NE.0) GO TO 410
      IGARBLE=1
      GO TO 200
 410  ICAR=1
C
C------INCREMENT TRAVEL ARRAYS
C
 500  TRP(1)=D
      TRP(4)=1.
      IF (IORIG.NE.IDEST) GO TO 510
      TRP(2)=D
      TRP(5)=1.
 510  IF (NDAY.LT.2.OR.NDAY.GT.6) GO TO 520
      TRP(3)=D
      TRP(6)=1.
 520  IF (IONITE.NE.0) TRP(7)=1.
      IF (IEXT   .NE.0) TRP(8)=1.
      DO 540 I=1,8
      DRIVEL(I,IDRVR)=DRIVEL(I,IDRVR)+TRP(I)
      IF (NCARS.NE.1) GO TO 540
      CARVEL(I,ICAR )=CARVEL(I,ICAR )+TRP(I)
 540  TRP(I)=0.
      IF (KONTROL(2).LT.3) GO TO 200
      PRINT 562
 562  FORMAT(1H0  5X 8HDRIVEL =  )
      DO 563 J=1,10
 563  PRINT 564,(J,(DRIVEL(I,J),I=1,8))
 564  FORMAT(I8,2X 8(F8.1,2X) )
      PRINT 566
 566  FORMAT(1H0 5X 8HCARVEL = )
      DO 567 J=1,10
 567  PRINT 564, (J,(CARVEL(I,J),I=1,8))
      GO TO 200
C
C------CLASSIFY DRIVERS AND CARS
C
```

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 600  IF (NTRIPS.EQ.0) GO TO 100
      IF (IGARBLE.NE.0) GO TO 820
      DO 604 IDRVR=1,10
 604  IF (DRIVEL(4,IDRVR).NE.0.) NDRVRS=IDRVR
 610  DO 618 J=1,NDRVRS
      DRIASS(1,J)=.TRUE.
      DO 612  I=2,6
 612  DRIASS(I,J)=.FALSE.
      IF (NDRVRS.GT.NCARS) GO TO 618
      DRIASS(2,J)=.TRUE.
      IF (NCARS.LT.5) DRIASS(NCARS+2,J)=.TRUE.
 618  CONTINUE
      DO 638  I=1,4
 638  CARASS(I,1)=.FALSE.
      IF (NCARS.NE.1) GO TO 700
      IF (NDRVRS.LE.3) CARASS(NDRVRS,1)=.TRUE.
      CARASS(4,1)=.TRUE.
C
C-----UPDATE TRAVEL DISTRIBUTIONS
C
 700  DO 740 J=1,40
      DO 720 IDRVR=1,NDRVRS
      IF (DRIVEL(1,IDRVR).LT.DST(J).OR.
     1    DRIVEL(1,IDRVR).GE.DST(J+1)) GO TO 710
      DO 706 I=1,6
 706  IF (DRIASS(I,IDRVR)) DISTDIS(I,J)=DISTDIS(I,J)+1.
 710  IF (DRIVEL(4,IDRVR).LT.TRIPNO(J).OR.
     1    DRIVEL(4,IDRVR).GE.TRIPNO(J+1)) GO TO 720
      DO 716 I=1,6
 716  IF (DRIASS(I,IDRVR)) TRIPDIS(I,J)=TRIPDIS(I,J)+1.
 720  CONTINUE
      IF (NCARS.NE.1) GO TO 740
      ICAR=1
      IF (CARVEL(1,ICAR).LT.DST(J).OR.
     1    CARVEL(1,ICAR).GE.DST(J+1)) GO TO 730
      DO 726 I=1,4
 726  IF (CARASS(I,ICAR)) DISTDIS(I+6,J)=DISTDIS(I+6,J)+1.
 730  IF (CARVEL(4,ICAR).LT.TRIPNO(J).OR.
     1    CARVEL(4,ICAR).GE.TRIPNO(J+1)) GO TO 740
      DO 736 I=1,4
 736  IF (CARASS(I,ICAR)) TRIPDIS(I+6,J)=TRIPDIS(I+6,J)+1.
 740  CONTINUE
C
C-----UPDATE DISTRIBUTION DESCRIPTORS
C
 800  DO 806 J=1,8
      DO 802 ICLASS=1,6
      DO 802 IDRVR=1,NDRVRS
 802  IF (DRIASS(ICLASS,IDRVR)) CONDIS(ICLASS,J)=CONDIS(ICLASS,J)
     1    +DRIVEL(J,IDRVR)
      IF (NCARS.NE.1) GO TO 806
      DO 804 ICLASS=1,4
 804  IF (CARASS(ICLASS,1)) CONDIS(ICLASS+6,J)=CONDIS(ICLASS+6,J)
     1    +CARVEL(J,1)
 806  CONTINUE
      DO 808 J=1,10
      DRVNAM(J)=0.
      DO 808 I=1,8
      DRIVEL(I,J)=0.
  808 CARVEL(I,J)=0.
      DO 814 ICLASS=1,6
      DO 814 IDRVR=1,NDRVRS
  814 IF (DRIASS(ICLASS,IDRVR)) CONDIS(ICLASS,9)=CONDIS(ICLASS,9)+1.
      DO 816 ICLASS=1,4
      ICAR=1
  816 IF (CARASS(ICLASS,ICAR)) CONDIS(ICLASS+6,9)=CONDIS(ICLASS+6,9)
     1   +1.
  820 IF (IGARBLE.NE.0) NGARBLE=NGARBLE+1
      IGARBLE=0
      NTRIPS=0
      IF (NGARBLE.GT.100) GO TO 900
      IF (ENDTRPS.EQ.1234.) GO TO 900
      IF (KONTROL(3).LT.1) GO TO 100
      CALL HEAD(3)
      PRINT 902
      PRINT 908, (DST(J),DST(J+1),(DISTDIS(I,J),I=1,10),J=1,40)
      CALL HEAD(3)
      PRINT 922
      DO 827 J=1,40
      JJ=J-1
  827 PRINT 928,JJ,(TRIPDIS(I,J),I=1,10)
      CALL HEAD(6)
      PRINT 944
      PRINT 946,  (CONDX(J),(CONDIS(I,J),I=1,10),J=1,9)
      PRINT 982, NHOMREC,NTRPREC,NPAR1,NPAR2,NGARBLE,NTAXTRP,NTRKTRP,
     1 NHOMIT,NOUSE,NOCARS,NOTRIPS,NOPERS,NTOMIT,NOZONE
      GO TO 100
C
C-----COMPLETE AND PRINT TRAVEL DISTRIBUTIONS
C
  900 CALL HEAD(3)
      PRINT 901
      PRINT 902
  901 FORMAT(42H PER CENT DISTRIBUTIONS OF DAILY TRAVEL -  // )
  902 FORMAT(                                                          ,
     1   36H   MILEAGE        ALL         DRIVERS
     2   45H     DRIVERS WITH CARS BY CARS PER HOUSEHOLD
     3   48H          ONLY CARS BY NUMBER OF DRIVERS             /
     4   36H    RANGE       DRIVERS     WITH CARS
     5   48H     ONE            TWO            THREE         FOUR
     6   48H     ONE            TWO            THREE         ALL          //)
      DO 906  I=1,10
      TOTAL(I)=0.
      DO 904 J=1,40
  904 TOTAL(I)=TOTAL(I)+DISTDIS(I,J)
      DO 905  J=1,40
  906 IF (TOTAL(I).NE.0.) DISTDIS(I,J)=100.*DISTDIS(I,J)/TOTAL(I)
      PRINT 908, (DST(J),DST(J+1),(DISTDIS(I,J),I=1,10),J=1,40)
  908 FORMAT(3XF4.0, 1H- F3.0, 1X10(F8.1,4X))
  910 CALL HEAD(3)
      PRINT 911
  911 FORMAT(52H CUMULATIVE PER CENT DISTRIBUTIONS OF DAILY TRAVEL - //)
      PRINT 902
      DO 916  I=1,10
      DO 916  J=2,40
916   DISTDIS(I,J)=DISTDIS(I,J)+DISTDIS(I,J-1)
      PRINT 908, (DST(J),DST(J+1),(DISTDIS(I,J),I=1,10),J=1,40)
920   CALL HEAD(3)
      PRINT 901
      PRINT 922
922   FORMAT(
     1   36H   NO. OF          ALL        DRIVERS
     2   48H      DRIVERS WITH CARS BY CARS PER HOUSEHOLD
     3   48H           ONLY CARS BY NUMBER OF DRIVERS           /
     4   36H    TRIPS       DRIVERS     WITH CARS
     5   48H      ONE            TWO          THREE        FOUR
     6   48H      ONE            TWO          THREE        ALL           //)
      DO 926  I=1,10
      TOTAL(I)=0.
      DO 924 J=1,40
924   TOTAL(I)=TOTAL(I)+TRIPDIS(I,J)
      DO 926  J=1,40
926   IF (TOTAL(I).NE.0) TRIPDIS(I,J)=100.*TRIPDIS(I,J)/TOTAL(I)
      DO 927 J=1,40
      JJ=J-1
927   PRINT 928,JJ,(TRIPDIS(I,J),I=1,10)
928   FORMAT(1X I6, 5X 10(F8.1,4X) )
930   CALL HEAD(3)
      PRINT 911
      PRINT 922
      DO 936  I=1,10
      DO 936  J=2,40
936   TRIPDIS(I,J)=TRIPDIS(I,J)+TRIPDIS(I,J-1)
      DO 937 J=1,40
      JJ=J-1
937   PRINT 928,JJ,(TRIPDIS(I,J),I=1,10)
C
C-----PRINT DISTRIBUTION CONDITIONS
C
940   CALL HEAD(6)
      PRINT 942
942   FORMAT(27H DISTRIBUTION CONDITIONS - // )
      PRINT 944
944   FORMAT(
     1   36H                   ALL        DRIVERS
     2   48H      DRIVERS WITH CARS BY CARS PER HOUSEHOLD
     3   48H           ONLY CARS BY NUMBER OF DRIVERS           /
     4   36H                    DRIVERS     WITH CARS
     5   48H      ONE            TWO          THREE        FOUR
     6   48H      ONE            TWO          THREE        ALL           //)
      PRINT 946, (CONDA(J),(CONDIS(I,J),I=1,10),J=1,9)
946   FORMAT(1X A10, 1X 10(F9.0,3X) )
C
C-----PRINT CAR/PARKING DATA
C
960   PRINT 962
962   FORMAT(1H0/1H0/1H0  31HCAR AND PARKING AVAILABILITY - //)
      PRINT 174
      PRINT 176, ((HHLABL(I,J),I=1,2),(HHDATA(I,J),I=1,8),J=1,6)
C
C-----PRINT MISCELLANEOUS RUN DATA
```

```
C
 980  CALL HEAD(5)
      PRINT 982, NHOMREC,NTRPREC,NPAR1,NPAR2,NGARBLE,NTAXTRP,NTRKTRP,
     1 NHOMIT,NOUSE,NOCARS,NOTRIPS,NOPERS,NTQMIT,NOZONE
 982  FORMAT(
     1    10X50H NUMBER OF HOUSEHOLD RECORDS PROCESSED              I8//
     1    10X50H NUMBER OF TRIP RECORDS PROCESSED                   I8//
     1    10X50H NUMBER OF PARITY ERRORS IN HOUSEHOLD DATA          I8//
     1    10X50H NUMBER OF PARITY ERRORS IN TRIP DATA               I8//
     1    10X50H NUMBER OF HOUSEHOLDS ASSOCIATED WITH GARBLED DATA  I8//
     1    10X50H NUMBER OF TAXI DRIVER TRIPS SKIPPED                I8//
     1    10X50H NUMBER OF TRUCK DRIVER TRIPS SKIPPED               I8//
     1    10X50H NUMBER OF HOUSEHOLDS SKIPPED                       I8//
     1    10X50H NUMBER OF SKIPPED HOUSEHOLDS WITH UNUSED CARS      I8//
     1    10X50H NUMBER OF SKIPPED HOUSEHOLDS WITH NO CARS          I8//
     1    10X50H NUMBER OF SKIPPED HOUSEHOLDS WITH NO TRIP DATA     I8//
     1    10X50H NUMBER OF SKIPPED HOUSEHOLDS WITH NO PERSONS       I8//
     1    10X50H NUMBER OF SKIPPED TRIPS WITH BAD ID                I8//
     1    10X50H NUMBER OF TRIPS OMITTED FOR BAD ZONE NAMES         I8  )
      CALL HEAD(3)
      STOP
      END PROGRAM AUTOUSE
      SUBROUTINE DECODER(DATA,NCHAR,NUMBER,KONTENT)
C
C          DECODES FIRST NCHAR BCD CHARACTERS OF DATA, RETURNS
C          NUMBER AND KONTENT AS FOLLOWS --
C
C          NUMBER    KONTENT   DATA
C          --------  --------  ------------------------------
C
C          (INT.)       1      ALL CHARACTERS NUMERIC
C             0         0      ALL CHARACTERS BLANK
C             0        -1      ALL CHAR. BLANK, -, OR X
C             0         3      CHARACTERS OTHER THAN ABOVE
C
C          IF NCHAR=1 AND DATA IS A LETTER, KONTENT IS SET TO 2 AND
C          NUMBER IS SET TO THE NUMBER OF THE LETTER IN THE ALPHABET
C
      DIMENSION IDIG(10),ICHAR(10)
      DATA (IDIG(I),I=1,10)/1,10,100,1000,10000,1000000,1000000,
     1 10000000,100000000,1000000000/
      DECODE (10,4,DATA) ICHAR
    4 FORMAT(10R1)
      N=1   $NN=NCHAR   $KONTENT=1   $NUMBER=0   $NULL=0   $NBLANK=0
      GO TO 11
   10 N=N+1   $NN=NN-1
   11 IF (ICHAR(NN).LE.1RZ) GO TO 40
      IF (ICHAR(NN).GT.1R9) GO TO 50
      IF (NULL.EQ.0) NUMBER=NUMBER+(ICHAR(NN)-1R0)*IDIG(N)
   20 IF (NN.GT.1) GO TO 10
      IF (NULL.EQ.0) RETURN
      NUMBER=0   $KONTENT=0
      IF (NBLANK.EQ.NCHAR) RETURN
      KONTENT=-1
      IF (NULL.EQ.NCHAR) RETURN
   30 NUMBER=0   $KONTENT=3    $RETURN
   40 IF (ICHAR(NN).NE.1RX) GO TO 70
      NULL=NULL+1
      GO TO 20
   50 IF (ICHAR(NN).NE.1R ) GO TO 60
      NBLANK=NBLANK+1
      NULL=NULL+1
      GO TO 20
   60 IF (ICHAR(NN).NE.1R-) GO TO 30
      NULL=NULL+1
      GO TO 20
   70 KONTENT=2   $NUMBER=ICHAR(1)
      IF (NCHAR.EQ.1) RETURN
      GO TO 30
      END SUBROUTINE DECODER
      SUBROUTINE DIST(I,J,D)
C
C CALCULATES DISTANCE D IN MILES BETWEEN POINTS I AND J.
C READS AND SCALES COORDINATE LIST IF I=0.
C RETURNS D EQUAL TO -1. IF ZONE I OR ZONE J IS NOT IN INPUT LIST.
C
      DIMENSION NM(7),CX(7),CY(7),CZ(7),NC(4,1240),C(4,1240),NREF(100)
      EQUIVALENCE (NC,C)
C
C CHECK FOR READIN OF COORDINATE LIST.  STOP IF READ ATTEMPTED TWICE.
      IF (I.GT.1000.AND.J.GT.1000) GO TO 100
      IF (FLAG.NE.123456789.) GO TO 10
      CALL HEAD(10)
      PRINT 5, I,J
 5    FORMAT(46X 28H* ERROR IN SUBROUTINE DIST */58X 3HI = I5,
     1 3X3HJ = I5 )
      STOP
C
C READ COORDINATE CARDS ONE AT A TIME.  NAME ON CARD APPLIES ONLY TO FIRST
C OF SEVEN COORDINATE PAIRS.  CONSTRUCT NAMES FOR SECOND AND SUBSEQUENT
C PAIRS SEQUENTIALLY AFTER FIRST NAME.
 10   FLAG = 123456789.
      SCALE = (2000./5280.)/100.
      NMAX=1240
      NPOINT=0
      NR = 0
      DO 14 I=1,4
      DO 14 J=1,1240
 14   C(I,J)=0.
C
      DO 40 NCARD=1,1000
      READ 22, NAME,((CX(I),CY(I)),I=1,7)
 22   FORMAT(I4,1X14F5.0)
      IF (NAME.EQ. 9999) GO TO 46
      DO 36 M=1,7
      IF (CX(M).EQ.0.) GO TO 40
      NPOINT=NPOINT+1
      IF (NPOINT.LE.NMAX) GO TO 33
      CALL HEAD(20)
      PRINT 28, NCARD,NPOINT
 28   FORMAT(42X36H***   TOO MANY POINTS FOR DIST    ***  //
     1    7HNCARD =  I5,  // 55X 7HNPOINT= I5)
      GO TO 46
C TO SPEED LOCATION OF GIVEN COORDINATE NAMES IN COORDINATE LIST, PLACE
C KEY NAME SUBSCRIPTS IN LIST NREF.  ASSUME POINT NAMES ARE FOUR-DIGIT NUMBERS
C STORE INDICES OF NAMES ENDING IN 00 IN SEQUENCE IN NREF.
 33   IF (NAME/100.LE.NR) GO TO 34
      NR=NR+1
      NREF(NR)=NPOINT
      GO TO 33
 34   NC(1,NPOINT)=NAME-1+M
       C(2,NPOINT)=CX(M)*SCALE
 36    C(3,NPOINT)=CY(M)*SCALE
 40   CONTINUE
C
      CALL HEAD(20)
      PRINT 45
 45   FORMAT(40X 41H***   TOO MANY INPUT CARDS FOR DIST   *** )
C
C ESTIMATE INTRAZONAL DISTANCES AS ONE-HALF OF CENTROID-TO-CENTROID
C DISTANCE FROM A ZONE TO ITS NEAREST NEIGHBOR.
 46   DO 48 N=1,NPOINT
      IF (C(4,N).NE.0.) GO TO 48
      DMIN=9999999999.
      DO 47 M=1,NPOINT
      IF (C(4,M).NE.0.) GO TO 47
      D=(C(2,N)-C(2,M))**2+(C(3,N)-C(3,M))**2
      IF (D.GT.DMIN.OR.M.EQ.N) GO TO 47
      MMIN=M
      DMIN=D
 47   CONTINUE
      C(4,N)=SQRT(DMIN)/2.
      C(4,MMIN)=C(4,N)
 48   CONTINUE
C
C PREPARE AND PRINT TABLE OF ZONE NAMES, COORDINATES, AND INTRAZONAL
C DISTANCES, 200 ZONES PER PAGE IN FOUR COLUMNS OF FIFTY EACH.
 50   NPTS=NPOINT
      KPAGE=0
 51   LINE=0
      KPAGE=KPAGE+1
      CALL HEAD(2)
      PRINT 52
 52   FORMAT(4(32H    AZ67   X POS   Y POS   INTRA     ) /
     1 4(32H    NAME      MI       MI       MI    ) // )
C
 55   LINE=LINE+1
      DO 58 KK=1,4
      K=KK-1
      I=LINE+50*K+200*(KPAGE-1)
      NM(KK)=NC(1,I)
      CX(KK)=C(2,I)
      CY(KK)=C(3,I)
      CZ(KK)=C(4,I)
      IF (I.GT.(NPTS-50)) GO TO 60
 58   CONTINUE
 60   PRINT 62, ((NM(I),CX(I),CY(I),CZ(I)),I=1,KK)
 62   FORMAT(4(I8,3F8.2))
      IF (I.EQ.NPTS.AND.KK.EQ.1) RETURN
      IF (LINE.LT.50) GO TO 55
      IF (LINE.EQ.50.AND.KK.EQ.4.AND.I.LT.NPTS) GO TO 51
      RETURN
C
C LOCATE NAMED POINTS IN COORDINATE LIST BY SEQUENTIAL SEARCH STARTING AT
C KEY NAME LOCATION STORED IN NREF.
 100  IR=I/100
      JR=J/100
      IF (IR.GE.100.OR.JR.GE.100) GO TO 190
      M=NREF(IR)
      N=NREF(JR)
C
 110  IF (NC(1,M).EQ.I) GO TO 120
      M=M+1
      IF (M.GT.NMAX) GO TO 190
      GO TO 110
C
 120  IF (NC(1,N).EQ.J) GO TO 150
      N=N+1
      IF (N.GT.NMAX) GO TO 190
      GO TO 120
C
C CALCULATE DISTANCE ASSUMING STRAIGHT LINE PATH FROM I TO 4.
 150  IF (M.EQ.N) GO TO 152
      D=SQRT((C(2,M)-C(2,N))**2+(C(3,M)-C(3,N))**2)
      RETURN
 152  D=C(4,M)
      RETURN
C
 190  D=-1.
      RETURN
      END SUBROUTINE DIST
      SUBROUTINE HEAD(N)
C
C HEADS PAGE WITH PROGRAM NAME, DATE, TIME, AND PAGE NUMBER, AND THEN
C SKIPS DOWN N LINES.  IF N IS BCD, STORES IT AS PROGRAM NAME INSTEAD.
C
      IF (N.LT.56.AND.N.GE.0) GO TO 50
      NAME=N
      CALL MDATE(DATE)
      RETURN
C
 50   KPAGE=KPAGE+1
      CALL MTIME(TIME)
      PRINT 55,NAME,DATE,TIME,KPAGE
 55   FORMAT(1H1 8HPROGRAM A10,21XA10,20XA10,22X4HPAGE I4)
      DO 57 I=1,N
 57   PRINT 58
 58   FORMAT(1H )
      RETURN
      END SUBROUTINE HEAD
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